A

TEXT-BOOK

OF

MEDICAL PHYSICS.

FOR THE USE OF STUDENTS AND PRACTITIONERS OF MEDICINE.

BY

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PREFACE.

The fact that a knowledge of Physics is indispensable to a thorough understanding of Medicine has not yet been as fully realized in this country as in Europe, where the admirable works of Desplats and Gariel, of Robertson, and of numerous German writers, constitute a branch of educational literature to which we can show no parallel. A full appreciation of this, the author trusts, will be sufficient justification for placing in book form the substance of his lectures on this department of science, delivered during many years at the University of the City of New York.

Broadly speaking, this work aims to impart a knowledge of the relations existing between Physics and Medicine in their latest state of development, and to embody in the pursuit of this object whatever experience the author has gained during a long period of teaching this special branch of applied science. In certain cases topics not strictly embraced in the title have been included in the text—for example, the directions for section-cutting and staining; and in other instances exceptionally full descriptions of apparatus

have been given, notably of the microscope; but in view of the importance of these subjects, the course pursued will doubtless be approved. Attention may be called to the paragraph headings and italicized words, which suggest a system of questions facilitating a review of the text.

In conclusion, the author will feel that his labor has not been in vain if the work should serve to call deserved attention to a subject hitherto slighted in the curriculum of medical education.

JOHN C. DRAPER.

MEDICAL DEPARTMENT OF THE
UNIVERSITY OF THE CITY OF NEW YORK.
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MEDICAL PHYSICS.

PART I.

MATTER AND ITS FORMS.

SECTION I.

PROPERTIES OF MATTER.

INTRODUCTION.

Derivation of physics—Relation to metaphysics—Relation to mathematics—Relation to chemistry—Relation to mechanics—Medical physics—Perception of physical phenomena—Divisions of physics—Matter defined.

1. **Derivation.**—The word physics is derived from φύσις, nature. It is the science of nature, or *natural philosophy.*

2. **Relation to Metaphysics.**—It is that branch of knowledge which has for its subject all things which exist independently of the mind's conception of them. It thus stands distinct from metaphysics, or the science which has for its subject the ideas which exist in the mind only.

3. **Relation to Mathematics.**—While many of the laws of physics may be discussed from a mathematical point of view, there is a broad difference between mathematics and physics. To illustrate this we quote the words of Herschel in his essay "On the Study of Natural Philosophy"—"A clever man, shut up alone, and allowed unlimited time, might reason out for himself all the truths of mathematics by proceeding from those simple notions of space and number, of which he cannot divest himself without ceasing to think. But he could never tell by any effort of reasoning what would become of a lump of sugar if immersed in water, or what impression would be produced on his eye by mixing the colors yellow and blue." The essential difference between the two sciences, therefore, is that physics is a science of observation and experiment, while mathematics may be evolved by the reasoning faculty alone.

Physics is an inductive science evolving a general principle from special facts.

Mathematics is a deductive science drawing a particular truth from a general principle. Mill says, mathematics is the most perfect type of the deductive method.

4. Relation to Chemistry.—Physics deals with all the phenomena and modifications which bodies present, so long as they are not changed in composition. In this respect it is separated from *chemistry*, which treats of the composition of bodies and the changes therein.

5. Relation to Mechanics.—Mechanics is that division of physics which treats of the principles involved in the construction and action of machines. In consequence, we find the term animal mechanics frequently applied to the consideration of those functions of the body which resemble the actions of machines.

6. Medical Physics discusses the laws and phenomena of physics, with which the physician should be acquainted, to understand the processes of life, and also those, a knowledge of which is necessary for the improvement of the hygienic condition of the community in which he lives. In evidence of the manifold and varied applications of physics in medicine, the following examples are cited:

1. The explanation of the function of respiration on the principles of pneumatics and diffusion of gases.
2. The influence of latent heat in the maintenance of a fixed temperature in all hot-blooded animals.
3. The dependence of the phenomena of circulation of the fluids of the body on the laws of hydrodynamics and hydraulics.
4. The application of the principles of capillarity to the explanation of absorption and secretion.
5. The explanation of the action of the locomotive system on the principles involved in levers, with the numerous forms of surgical apparatus dependent on levers and wedges.
6. The elucidation of the action of the organs of vision and of hearing, by the laws of optics and acoustics.
7. Last though not least, the relations of meteorology to animal heat, and to the appearance, advance, and retrogression of various diseases.

Many other examples might be offered to show that physics rivals, if it does not surpass chemistry in the explanation of the phenomena of life. It is no exaggeration to say that there is not a tissue, organ, or function of the body, the proper comprehension of which does not involve a knowledge of the laws of physics. We may with equal justice affirm that there is scarcely a principle of physics which is not applied in some form in the human body. The importance of the study of this

department of science will, therefore, be self-evident to every true student and practitioner of medicine.

The disregard which physicians in the United States have hitherto shown, for even a superficial knowledge of physics, is unpardonable. This arises in part from the newness of the country, and the desire to make money quickly. It may be said that, outside of our great cities, very few practitioners of medicine have any conception of their true relations to the community in which they live. They move in a narrow groove, and their knowledge is founded almost exclusively on personal experience.

The title, physician, has honorably escaped the odium, that has fallen on that of doctor. Every quack, or charlatan, calls himself a doctor, and those who believe in him yield to his assumption. Not so with the title of physician. The word, by its derivation, means, one having a knowledge of nature, and to be physicians in the true sense of the term, we must extend our knowledge and influence beyond the mere empirical practice of the healing art.

The true physician is the man of science in the community in which he lives. He interests himself in the sanitary conditions of his vicinity. He warns his people regarding the deadly germs that may exist in the water they drink, and in the air they breathe. He insists on the proper ventilation and warming of their public and private buildings. He shows them the importance of careful removal of all offal and sewage from their houses, and how it should be done. He teaches them how to distinguish wholesome from unwholesome food, and how to prepare it so as to present the highest nutritive value. As far as in his power lies, he wards off the approach of disease, and seeks to improve hygienic conditions, so that the power to resist disease may be as perfect as possible. To accomplish this work properly, he must have knowledge, not only of the principles of physics connected with the functions of the interior of the economy, but also of those which offer the most favorable conditions for the maintenance of health.

7. Perception of Physical Phenomena.—The phenomena persented by bodies generally affect one or more of our special senses *directly*, as when they are sonorous, warm, luminous. Sometimes the changes can only be perceived *indirectly*, as, for example, when a mass of soft iron becomes magnetic, the change is best detected by its altered relation to other masses of iron, which it now attracts; whereas it failed to do so before the magnetism was developed.

8. Divisions of Physics.—The study of physics arranges itself naturally under two divisions. The first of these deals with the

things or objects acted upon. These are grouped together under the general head of *matter*. The second treats of *energy*, or the origin of the forces which act upon matter, and produce the varied phenomena which matter presents for our consideration and examination.

Professor Tait says: "The fundamental notions which occur to us when we commence the study of physical science, are those of *time* and *space*. In relation to these, algebra has been called the science of pure time, and geometry of pure space." The study of the special mixed science of space and time is called *kinematics*.

Close upon our ideas of time and space follow those of matter, position, motion, force. Of these, *position* is a space relation or geometrical conception. *Motion* is change of position, which, since it varies in rate, implies the idea of time as well as space. They are both independent of our conceptions of matter and force, or rather of *energy*, which may be defined as the power of doing work, or, as Tait puts it, "of doing mischief;" and which we may regard as the cause of force.

"As silver and gold are different forms of matter, so sound, heat, light, etc., are now viewed as different forms of energy. It is this *idea* which enables us to coördinate the apparently diverse sciences which constitute physics. In its application we are ever obliged to be on our guard, in respect to the manner in which we treat the evidences afforded by our sensations. Take, for example, sound and light; until they affect certain special senses they are wave-motions. The sensation is as different from the cause, as the pain produced by a cudgel is different from its motion."

So intimate are the relations between matter and energy, that it is impossible to consider matter, without at the same time dealing with certain forms of energy, as attraction and motion, which are inseparable from and inherent in matter. We shall, therefore, as occasion arises, examine the leading features of these two forms of energy, as far as is necessary for the proper comprehension of the constitution and forms of matter, and reserve their more detailed study to the division of energy proper.

9. Matter Defined.—*The most concise definition of matter is that it is anything which may be perceived by one or more of our special senses as occupying space.* Everything not so perceptible is called immaterial. We may, perhaps, best realize the difference between the terms material and immaterial by an example; so, while the body is material, the mind or the soul is immaterial; while the universe presents the material on its grandest scale, the creator and ruler becomes to us the noblest illustration of the immaterial. The pride which we feel in our accumulated knowl-

edge is humiliated, when we realize how incompetent our finite minds are to grasp the ideas presented by the universe and its creator. We may, it is true, fathom the meaning of space, so long as it is confined to measurements which we can execute; but infinite space like that embraced by the universe surpasses our comprehension. Time may be realized while limited to small portions of the brief span comprised in a lifetime; but no human mind has ever compassed the idea of eternity, that endless time, before which even the grandest intellect stands humbled and appalled. So energy in its turn may be realized while it remains shackled within the control of our individual physical powers, but we cannot frame the first conception of an energy, or a force which is almighty, which governs the universe, regulates the motions of planets and suns, and which many imagine may even have created matter.

CHAPTER I.

STRUCTURE OR CONSTITUTION OF MATTER.

Subdivisions of matter—Mechanical subdivision—Particles—Minute living organisms—Subdivision by solution—Chemical subdivision—Atom and molecule defined—Origin of the idea of atoms—Cohesion—Effects of heat and pressure on matter—The molecules do not touch—Motion among molecules—Theory of the structure of matter—Relative sizes of molecules and interstices—Estimated actual sizes of molecules and interstices—Imperfection of so-called vacua—Omnipresence of matter.

To understand the changes which matter presents, and the influence of forces thereon, it is necessary to determine the structure or constitution of matter. By means of the following experiments and investigations, we shall arrive at a satisfactory solution of this problem.

10. Subdivision of Matter may be of three kinds, or degrees, according to the methods employed. These are: 1, Mechanical means of various kinds; 2, Solution either of a solid in a fluid, or of a solid or fluid in air; 3, Chemical processes.

11. Mechanical Subdivision.—If we place a portion of chalk in a porcelain mortar and pound it with the pestle, it breaks into

fragments, which become smaller and smaller as the pounding or blows are continued, until finally the whole mass is reduced to a coarse powder. This process is known as *pulverization.* To reduce the coarse to a fine powder, the contents of the mortar are submitted to a grinding operation, by rubbing them in the mortar with the pestle. This is called *trituration.* Many other methods of mechanical subdivision will suggest themselves, but these answer our purpose for the present.

12. Particles.—The fine powder produced by trituration, though it appears to be impalpable, if examined under the microscope with a sufficiently high power is seen to be made up of minute masses, which are called particles. *A particle* may, therefore, be defined as *the minutest subdivision of matter attainable by mechanical means.* In the case of mercury this subdivision may be carried on until the globules are less than the $\frac{1}{20000}$ of an inch in diameter, as in blue mass. The smallest single particle discoverable by the normal unassisted human eye is generally stated to be about $\frac{1}{2000}$ of an inch in diameter. In this method of subdivision the particles retain all the physical properties presented by the original mass, viz., the color, hardness, etc., being unaltered.

13. Minute Living Organisms.—Though our senses can with difficulty appreciate the minuteness of the particles attainable by mechanical subdivision, yet these are rivalled and even exceeded in smallness by innumerable living organisms. The red corpuscle or disks which are found in human blood, for example, are often $\frac{1}{4000}$ of an inch in diameter and scarcely $\frac{1}{12000}$ of an inch thick. One of the most minute of the animalcules is the *monas crepisculum*, or twilight monad. This little creature is carnivorous in its habits, its globular body is sometimes only $\frac{1}{16000}$ of an inch in diameter, yet it has distinct organs, made up of innumerable particles, and thereby shows us that small as are the particles attainable by mechanical subdivision, there are subdivisions which are infinitely more minute.

14. Subdivision by Solution.—If we take one-tenth of a grain of indigo and dissolve it in a little strong sulphuric acid, it will give a blue tint to five hundred ounces of water. Such a solution contains less than one-millionth of a grain of coloring matter to the drop of fluid. It is even estimated that in this case the particles of indigo are only $\frac{1}{5000000000000000}$ part of a cubic inch in size.

When a grain of musk is exposed in a room it will give its characteristic odor to the air of the apartment for many months,

yet at the close of that time it will have lost only a small fraction of its weight.

In these examples of subdivision and diffusion of one material throughout another, we have in reality separated the ultimate particles of one substance from each other by introducing between them one or more exceedingly minute particles of another substance. If the dissolving material is vastly greater in mass than that dissolved, we may even approach the smallest degree of subdivision of which the dissolved body is capable, and still retain its properties. To this degree of subdivision the term *molecule* is applied.

15. Chemical Subdivision.—Taking a portion of the chalk powder produced by mechanical subdivision (11), and pouring dilute hydrochloric acid upon it, a violent effervescence is produced, and at last the chalk disappears. Testing the nature of the escaping gas, we find that it is carbonic acid gas, or carbon dioxide, while the lime of the chalk remains in the solution formed. In this case we have by chemical action torn the molecule of chalk asunder and produced therefrom a molecule of carbon dioxide and a molecule of calcium chloride. In the same manner, we may by suitable methods separate the carbon dioxide into the two bodies, carbon and oxygen. Here our power ceases for the present, but we have learned that the molecule of calcium carbonate forming the chalk was not the last stage of separation of which that body was capable. From it we set free the gaseous carbonic acid, which in its turn was divisible into carbon and oxygen, and since we cannot separate either of these into simpler bodies we call them *elements*. With these facts before us, we are prepared to understand what is meant by an atom and a molecule.

16. Atom and Molecule Defined.—*An atom is the smallest conceivable portion into which an elementary body can be divided, or the smallest portion of an element that can enter into combination.*

While we may conceive of an atom of oxygen or of any other elementary body, modern chemistry teaches us that a single atom never exists in the free state; it is always combined with one or more atoms of the same, or of a different kind. The smallest possible free portion of oxygen must, therefore, consist of at least two atoms of this body, and we speak of this as a molecule of oxygen; we may consequently say that *a molecule is composed of atoms, and is the smallest portion of a substance capable of a separate existence.* The term molecule may be applied both to elementary and compound substances, while the idea of an atom is only applicable to elements.

17. Origin of the Idea of Atoms.—The conception of the atom descends to us from the ancient Greeks, though it probably originated in India, where doctrines similar to the centres of force of Boscovich have been subjects of discussion from very remote times. Among the early students of atoms was Leucippus. He adopted the theory of atoms because all arguments in favor of infinite divisibility necessarily ended in empty words, or in incomprehensible thoughts.

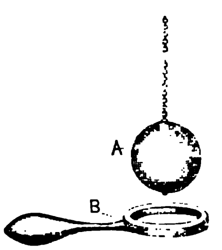
18. Cohesion.—For the subdivision of matter we have seen that force is necessary. It is, therefore, evident that some opposing force exists in matter by which its molecules are united, or bound together. To this the name of cohesion has been given.

Let a small sheet of glass, three or four inches square, be suspended by threads and so adjusted that its surfaces are in a horizontal plane. Then let the lower surface of the glass be brought in contact with water. The glass and water immediately attract each other, and a certain amount of force is required to separate them.

In this case we have apparently shown the attraction between glass and water; but if we examine the experiment more carefully, we find that the lower surface of the glass is covered with a layer of the liquid. It is, therefore, evident that we have not separated the glass from the water, but we have torn the molecules of water asunder, and the force required to do this was the measure of their cohesion for each other.

19. Effects of Heat and Pressure on Matter.—Seeing that all matter is composed of molecules, the inquiry naturally arises, What is the relation of these to each other as regards position? Are they in contact, or are they at a distance from each other? An answer to this question is offered by the following experiment, delineated in Fig. 1. Let A be a sphere of brass, two or three inches in diameter, made as true as possible, and suspended by a chain. To the sphere, A, a metallic ring, B, is adapted, which at ordinary temperatures permits the sphere to pass through it easily. On raising the temperature of the sphere by means of a spirit or a gas flame, and then attempting to pass it through the ring, we find that it will no longer do so. From this we conclude that the metallic sphere has increased in size under the influence of the rise in temperature. Allowing the mass to cool, it again passes through the ring without

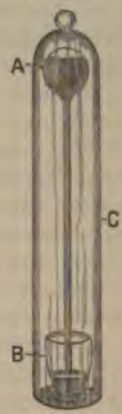
FIG. 1.



Expansion by heat.

difficulty. It has therefore diminished in volume by the diminution in temperature. In like manner, variations in pressure cause variation in volume. In illustration of this, take a tube one inch in diameter with a bulb, A, expanded on one end. The tube and bulb are almost entirely filled with water, which confines a bubble of air in the upper part of the bulb or sphere. The lower part of the tube dips under the surface of the water in a vessel, B, and thus the fluid is suspended in the tube and bulb. Placing this instrument under a tall air-pump bell, C, and proceeding to exhaust, the bubble of air dilates, and the fluid retreats into the tube, and vessel, B. Restoring the pressure of the atmosphere, the bubble of air at A contracts, and the fluid returns to its original position.

FIG. 2.



Expansion by reduced pressure.

20. The Molecules do not Touch.—The only explanation of the phenomena presented in the preceding article is that the air in the bulb has expanded and contracted, under the influence of the variations in pressure. This it could not do if the molecules were in contact with each other. We, therefore, arrive at a correct answer to the question propounded in the last article, and conclude that the molecules both in the solid and in the gas, cannot be in contact, but are separated by spaces or intervals, called *interstices*.

21. Motion among Molecules.—The expansion and contraction obtained in the preceding experiments, show that the molecules are mobile in the solid as well as in the gas. Numerous instances of mobility among the molecules of solids suggest themselves, but none is of greater interest than those which occur in the case of periodide of mercury which has been recently sublimed.

If a little of this substance be placed in a test-tube and heated, its color changes to a bright yellow. After a few moments it vaporizes, and, recondensing higher up in the tube, forms a yellow sublimate. Under these conditions of temperature there is, of course, no moisture present on which to base an explanation of what follows. If the yellow sublimate be touched with any hard substance, it instantly turns red, owing to a rearrangement of the molecules of periodide among themselves. Even without the act of touching, the sublimate will in time undergo a complete change of tint, passing from yellow to a brilliant red. Arsenious oxide also offers an example of

the same fact, changing slowly from a glassy amorphous into an opaque crystalline form.

Phenomena like these demonstrate that in solids, molecular movements are not only possible by virtue of external interference, but they may also arise without any apparent initiating act. The most rational explanation of the changes in the periodide of mercury is, that even in the yellow state, molecular oscillations or vibrations are occurring, and the change to the red state is merely dependent on some slight change in the manner or character of these movements.

If the idea of movement in connection with molecules be granted in the most solid bodies, we have an explanation of the manner in which the interstices (20) are maintained. For motion to exist, the molecule must have space in which to vibrate, hence the interstice. Increase the temperature, and the motion or vibration increasing, the interstitial spaces also increase, and the body expands. Diminish the temperature, the amplitude of motion of the molecule diminishes, the cohesive force draws the molecules together, the interstices diminish, and the body contracts.

Collecting the experiments and arguments embraced from article 11, and condensing them, we have the following:

22. Theory of the Structure of Matter.—1. *All matter is composed of molecules made up of atoms.*

2. *These molecules do not touch each other, but are separated by spaces, called intermolecular interstices.*

3 *The molecules forming a substance are never at rest, but are oscillating or moving in various ways, with inconceivable rapidity.*

4. *The molecules are drawn toward each other by a force called attraction or cohesion* (18), *which tends to diminish the size of the interstices.*

5. *The molecular movements resist the attractive or cohesive force. These motions are increased by the action of heat, and the size of the interstices is consequently increased. According as the cohesive force or the motion predominates, so does the size of the body vary.*

23. Relative Sizes of Molecules and Interstices.—By the action of heat, one cubic inch of water may be made to yield a cubic foot of steam. In its vaporous state the water molecules have the same chemical composition as in the fluid condition; the difference is the result of the expansion which the interstices between the molecules have undergone. This, and innumerable other examples, show how great the size of the interstices must be, compared with that of the molecules. In the case of dilated hydrogen gas this excess in size of the interstices is

enormous; some have even compared their relations to that existing between the planets of our solar system and the distances separating them.

24. Estimated Actual Sizes of Molecules and Interstices.—Sir William Thomson estimates that in ordinary solids and liquids the average distance between contiguous molecules is less than the millionth of a millimetre. In an article by Mr. G. J. Stoney ("Phil. Mag.," series 4, vol. 36), on the "Internal Motions of Gases Compared with Motions of Waves of Light," the author estimates that there are not fewer than a unit—eighteen, (unit) 18, or 1,000000000000000000 molecules in each cubic millimetre of a gas at ordinary temperatures and pressures. Considering that a cubic millimetre is about one-twentieth of an inch square on each face, we gain a faint conception of the marvellous minuteness of molecules.

25. Imperfection of So-called Vacua.—Admitting that a cubic millimetre of air or gas contains a (unit) 18 molecules, it is evident that the so-called barometric vacuum is sadly misnamed. The admirable exhaustion obtained by Crookes in the preparation of his radiometer tubes is equivalent to the almost inconceivable pressure of $\frac{1}{1000000}$ of an atmosphere, yet even at this reduction of pressure a cubic millimetre still contains 1,000000000000 molecules of gas.

26. Omnipresence of Matter.—The imperfections of our best vacua (25) show that is hardly possible to conceive of space as existing without matter. In other words, matter is omnipresent. If there be any doubt of the truth of this, a glance at the stars should reassure us. Distant though they be from us and from each other, there is no part of the heavens that is not studded with them. Increase in the power of telescopes only serves to reveal to our astonished gaze innumerable stars and nebulæ, which before were invisible. The wave theory of light, too, demands the existence of the *ether*, or an exceedingly attenuated form of matter existing throughout space, and in which light is propagated by oscillations or vibrations of its molecules.

With more truth than he kenned, did Milton in his "Paradise Lost" cause the Almighty to exclaim:

> "I am who fill
> Infinitude, nor vacuous the space
> Though I myself retire."

CHAPTER II.

ULTIMATE COMPOSITION OF MATTER.

Elements and compounds defined—Theory of the oneness of matter—Hydrogen the original element—Nature of atoms.

27. Elements and Compounds Defined.—In examining chemical subdivision (15), we have seen that there is a limit to the subdivision of a body as regards its constituents. In the case of calcium carbonate, for example, we arrive finally at calcium, carbon, oxygen. These we cannot separate into other and simpler bodies; though it is possible that such a result may some day be accomplished. Many substances once thought to be undecomposable have since been separated; the same may happen in other cases; we may, therefore, say that:

An element is a body which has not yet been decomposed, while:

A compound is made up of two or more elements.

28. Theory of the Oneness of Matter.—While the discussion of the composition of bodies and the changes therein belongs properly to chemistry, there is one view regarding the origin of elements which places this question within the domain of physics.

The chemist claims the existence of some sixty-five distinct elements, out of which all the objects on the globe are constructed. These he believes "no kind of alchemy will transmute the one into the other." In discussing this, Dr. Arnott says:

"How sixty-five kinds of matter should, by variously combining, form the endless diversity of things and appearances which our globe presents is not without analogy. All the words, all the literature of the English tongue is formed out of twenty-four letters, and all the letters of the multitude of tongues on the face of the earth are not more in number than the chemical elements. Even more wonderful is the fact that all the words of the English, or any other language, may now be signalled along a telegraph wire by combinations of only two different signals, a long and a short one." He might have added that the long signal, or dash, is itself a combination of short signals or dots.

The human invention of written language indicating not only

all the objects on the globe, but also expressing the thoughts, emotions, and passions with which man is endowed, is, as we have seen, reducible to a system of dots variously arranged. There is, therefore, nothing unwarrantable in the conception that the various kinds of matter, the presence of which we express by the proper arrangement of the same kind of dots in telegraphy, may be composed of one kind of elementary atom, and our so-called elements are mere modifications of this. The atoms we may say have their analogues in dots, molecules in letters, and substances in words.

The astrologers of the East not only evolved the idea of the atom, but their long-continued observations of the ceaseless movements of the heavenly bodies led them to believe that in the same way atoms or molecules of matter were never at rest (21). They even carried the similitude further, and taught that as the stars of the firmament were alike in appearance, so matter was all made up of one kind of atom, and the differences in different kinds were merely the results of difference in the kind of motion to which the elemental atom was subjected. The elemental atom, moreover, constituted the original or universal ether.

Among the Greek philosophers, Leucippus, of whom we have already spoken (17), held that the idea of the atom as the elementary substance gave a foundation on which, by the aid of eternal motion, combination, and separation, all material phenomena might be built, and their relations explained. The effect of motion in all its variety upon matter is finally summed up by Heraclitus in the saying that "Life is motion." "Nothing is, but as movement." It is to thoughts like these that we must attribute the search by the alchemists for the "Philosopher's Stone," and the "Elixir of Life." By the first they hoped to turn the base metals into gold; by the latter, to renew their youth and prolong life to a thousand years or more.

Of modern thinkers the eminent physicist and chemist Graham, was a leading upholder of the "Oneness of matter and the power of motion and combination to produce diversity." He, moreover, conceived the idea that the diversity in motion was the only basis of diversity in matter, or, in other words, that an atom constituted an element of a special kind, according to the rate or the peculiarity of its movements.

The theory of the oneness of matter is of especial interest to the physician, since it bears a close analogy to what he finds in the structure of all living organisms. Tracing the higher animal and vegetable structures back through their course of development to their first genesis, we find that they are composed of, and that they originate from, cells. In their structure the resemblance of these cells to each other is very close.

Whether it be a nerve-cell in the brain, a muscle-cell, a cell of tendinous or cartilaginous tissue, or even of bone itself, in its first inception it consists of the same parts, viz., cell-wall, contents, nucleus, and nucleolus. From mere cells, the multiplicity of forms composing the organic world is evolved, *Omnia ex ovo* being the motto on which nature seems to work out her plans.

To the analogy here drawn exception might be taken, to the effect that these cells are, after all, essentially different. Though they resemble each other in that they are composed of the same parts, they are different in size and form. We never, it might be said, find muscle-cells producing a serous membrane, nor nerve-cells forming muscle. They therefore differ essentially from each other, just as iron differs from copper; indeed, they might be regarded as the analogues of the atoms of elements, each building up its own special form of structure, and none other.

Admitting, for the moment, this apparent objection, let us trace the genesis of the tissues of any organism a step further back, and for our example take man himself. The first differentiation of a human being consists of the formation of an ovum in the ovary of the female. To all appearances, this is nothing more nor less than a simple cell, and not distinguishable from similar ova of innumerable other animals, we might even say of plants also. Brought in contact under suitable conditions with its proper spermatozoa, which seem to bear to the ovum the same relation that energy bears to matter, and furnished with a formless material as food, changes begin. What was at first a simple cell, by the act of subdivision becomes an infinite number of cells. In the mass so produced, the embryo is outlined little by little. Tissue after tissue, each with its own peculiar cells, appears. Finally the perfect fœtus is formed. The child is born, and we are in the presence of the most wonderful of all creations, marvellously complex in its structure, possessing absolute characteristics which separate it from all other creatures; and yet all this complexity of structure has arisen from a single simple cell. Cells of brain, muscle, tendon, cartilage, bone, all have originated from the same source. No two elementary bodies differ from each other more than brain differs from cartilage, yet brain and cartilage have been evolved from the same original cell. Is it any greater wonder to imagine that as such divers tissues as those we have mentioned have all originated from one cell, our so-called elementary bodies may have also originated from one ultimate element?

Pushing the analogy still further, we arrive, in the organic world, at that curious body called protoplasm, from which the cell itself is produced, and which forms the completed body of an amœba and a moner. Whatever opinions we may hold regard-

ing differences among cells, none can exist concerning the uniformity of protoplasm, from whatever source it may be obtained. A mere formless, jelly-like material, without visible organization, it may be conceived to be the analogue of that something which we conceive to be distributed throughout space. We may further imagine that as cells are differentiated from protoplasm, so elementary atoms arise from an ultimate element, and as the cell once differentiated retains its special form and properties, which cannot be changed or altered by any agency at our command, so elementary atoms, in like manner, when once differentiated resist all our attempts at modification by the means we at present possess.

29. Hydrogen the Original Element?—In the "American Journal of Sciences and Arts," 3d series, vol. xviii. p. 96, there is a report of a paper read by J. Norman Lockyer, before the Royal Society, on December 12, 1878. It is entitled "On the Supposed Compound Nature of the So-called Elements." In this paper he says: "There are many facts and many trains of thought suggested by solar and stellar physics, which point to the hypothesis that the elements themselves, or at all events, some of them are compound bodies." The original element would appear to be hydrogen, for the spectrum analysis of the hottest stars shows this gas to be present in enormous quantity, with very little else, while stars of lower temperature show a less proportion of hydrogen, but present other elements the variety or number of which increases as the temperature descends. In the stars of the highest temperature other elements have not been formed, or they have been dissociated into hydrogen.

Observations by Prof. Piazzi Smyth, in another direction, tend to the same conclusion. In the "Observatory," for October, 1880, he states that in experiments with low temperature vacuum-tubes, after a prolonged passage of the electric spark, "Chlorine has been changed into hydrogen, and nitrogen though more slowly, seems to be going the same way. Is nitrogen after all not an element, but a compound? Is nitrogen merely a particular form or state of hydrogen?"

These opinions show that the tendency of modern thought is toward the acceptance of a modification of the ancient doctrine of the oneness of matter, and though it may not be a proven fact, we cannot deny that there are many phenomena which support the idea of the origin of other elements from hydrogen.

30. Nature of Atoms.—On this subject, says Professor Tait, various opinions have been held. "Among these, the first is that of the *perfectly hard atom*. You meet with it not only long before the time of Lucretius, but also in all subsequent

time, even in the works of Newton himself. We find Newton speculating on this subject in his unsuccessful attempt to account for the extraordinary fact that the velocity of sound, as calculated by him by strictly accurate mathematical processes, was found to be something like one-ninth too little. We find Newton suggesting that possibly the particles of air may be little, hard, spherical bodies, which, at the ordinary pressure of the atmosphere, are at a distance from one another of somewhere about nine times the diameter of each; and he says sound then may be propagated instantaneously through these hard atoms or particles of air, while it is propagated with the mathematically calculated velocity through the space between each pair. But, unfortunately for this explanation, it implies that sound should move faster in dense than in rare air at the same temperature. This is inconsistent with the results of direct measurement."

"It is obvious, that if there are such small infinitely hard particles as atoms, they must be in all bodies at a distance from one another, because, so far as experiment has guided us, there is no portion of matter whatever that is not capable of further compression by the application of sufficient pressure; and, of course, compression of a group of infinitely hard particles must presuppose that they have certain interstices between them, so that they are capable of being brought still nearer" (23 and 24).

"Another school of philosophers and experimenters, recoiling from the notion of the hard atom, took up the following idea. All that we know of atoms will be perfectly well accounted for if we dispense altogether with the notion of an atom—dispense with anything material in the ordinary sense of the word matter—but suppose merely *a centre of force*, such as we are accustomed to in those mathematical fictions which we meet with in our text-books. Suppose, in place of an atom, a mere geometrical point, which can exert repulsive or attractive forces, or rather suppose such forces tending toward or from a certain point, but nothing at the point, except, in some unexplained way, mass. So far as external bodies are concerned, this will behave just as an atom would do. That explanation was taken up and developed to a great extent by Boscovich, and was, to a certain extent, adopted in later times even by Faraday. It is, as I have stated at the outset, a mathematical fiction, but it is often an extremely convenient one for the purpose of enabling us to make certain mathematico-physical investigations of what takes place in the interior of bodies in their various states of solids, liquids, and gases."

A third hypothesis is that of the *vortex atom*, recently suggested by Sir William Thomson. Of this, Professor Tait says: "The peculiar properties of vortex-motion were mathematically

deduced for the first time by Helmholtz. It is necessary to give a brief sketch of his results in order that you may easily follow my explanation of Sir William Thomson's suggestion, and I do so the more readily because it is, or, at all events, it appears to myself to be by far the most fruitful in consequences of all the suggestions that have hitherto been made as to the ultimate nature of matter. Especially does it give us a glimpse, at least, of an explanation of the extraordinary fact, that every atom of any one substance, wheresoever we find it, whether on the earth or in the sun, or in meteorites coming to us from cosmical spaces, or in the farthest distant stars or nebulæ, possesses precisely the same physical properties."

"As a preliminary illustration, I shall show the formation of a simple circular vortex-ring, exhibiting one or two of its more important properties."

FIG. 3.

Vortex-rings.

"The apparatus consists of a very homely arrangement, merely a wooden box with a large round hole made in one end of it, while the opposite end has been removed and its place supplied by a towel tightly stretched. In order to make the air which is to be expelled from this box visible, we charge it first with ammoniacal gas, by sprinkling the bottom of the box with strong solution of ammonia. A certain quantity of ammoniacal gas has now been introduced into it, and we shall develop in addition a quantity of muriatic acid gas. This is done by putting into the box a dish containing common salt, over which I pour sulphuric acid of commerce. These two gases combine, and form solid sal ammoniac, so that anything visible which escapes from the box is simply particles of sal ammoniac, which are so very small that they remain suspended by fluid-friction, like smoke in the air. Now notice the effect of a sudden blow applied to the end of the box opposite the hole. There you see a circular vortex-ring moving on its own account through the room as if it were an independent solid."

"I shall now try to show the effect of one vortex-ring upon

another, just as I showed it here to Thomson, when he at once formed his theory. You notice that when two vortex-rings impinge upon one another, they behave like solid elastic rings. They vibrate vehemently after the shock, just as if they were solid rings of India-rubber. It is easy, as you see, to produce such vibration of a vortex-ring without any impact from another. All we have to do is to substitute an elliptical, or even a square hole, for the circular one we have hitherto employed."

"Now, the first vortex-ring which you saw sailing up through the class-room, contained precisely that particular portion of air, mixed with sal ammoniac powder, which had been sent out of the box by the blow. It was not merely sal ammoniac powder which was going through the air, but a certain definite portion of the smoky air, if we so may call it, from the inside of that box, which, in virtue of the vortex-motion which it had, became, as it were, a different substance from the surrounding air, and moved through it very much like a solid body."

"In fact, according to the result of Helmholtz's researches, if the air were a perfect fluid, if there were no such thing as fluid-friction in air, that vortex-ring would have gone on moving forever. Not only so, but the portion of the fluid which contained the smoke; which was, as it were, marked by the smoke, would remain precisely the same set of particles of the fluid as it moved through the rest; so that those which were thus marked by the smoke were, by the fact of their rotation, distinguished or differentiated from all the rest of the particles of air in the room, and could not by any process, except an act of creative power, be made to unite with the fluid in the room."

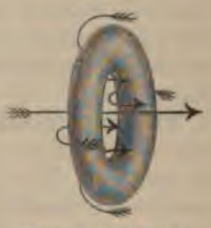
"That is a point which appears to me to be one of the most striking characteristics in the foundation of this suggestion of vortex-atoms. Granted that you have a perfect fluid, you could not produce a vortex-ring in it; nor, if a vortex-ring were there, could you destroy it? No process at our command could enable us to do either, because, in order to do it, fluid-friction is essentially requisite. Now, by the very definition of a perfect fluid, friction does not exist in it."

"Thus, if we adopt Sir William Thomson's supposition, that the universe is filled with something which we have no right to call ordinary matter (though it must possess inertia), but which we may call a perfect fluid, then, if any portions of it have vortex-motion communicated to them, they will remain forever stamped with that vortex-motion; they cannot part with it; it will remain with them as a characteristic forever, or at least until the creative act which produced it shall take it away again. *Thus this property of rotation may be the basis of all that to our senses appeals as matter.*"

"In such a vortex-ring (as you will easily understand by

thinking how it came out of the round hole in the box), the motion of the particles of air is of this kind. Suppose it to be coming forward towards you, then every portion of the air on the inner side of the ring is moving forward, and every portion on the outer side is moving backward, so that the whole is turning round and round its linear circular core. The air all about it is in motion according to a very simple law, which, however, I could not explain without mathematics—except in the particular case of that within the annulus, which is moving forward faster than the ring itself. I shall afford any of you who desire it an opportunity of convincing yourselves of the fact. Each of you will find that, if he places his face in the path of one of these large air vortex-rings, there is no sensation whatever until the vortex-ring is almost close to him, and when it reaches him he feels a sudden blast of wind flowing through the centre of it. Thus this vortex-ring not only involves in itself rotating elements which are thereby distinguished altogether from the other elements of the fluid, but it also is associated necessarily with other movements through the non-differentiated air, and especially a forward rapid current of air passing through its centre in the direction in which it is going. Helmholtz showed that if vortex-filaments exist in a continuous medium of any kind, they must be ring-shaped—that is to say, endless—after any number of knottings or twistings, the ends must come together. All vortex-rings—and, therefore, according to Sir William Thomson, all atoms of matter—must necessarily be endless—that is to say, must have their ends finally united together after any number of convolutions or knots."

FIG. 4.



Vortex-ring, structure.

"Secondly, though this is really involved in what we have just seen, Helmholtz shows that such a ring is indivisible; you cannot cut it. Do what you like; bring the edge of the keenest knife up to it as rapidly as you please, it cannot be cut; it simply moves away from or wriggles round the knife; and, in this sense, it is literally an atom. It is a thing which cannot be cut; not that you cannot cut it; but that you cannot so much as get at it so as to try to cut it."

In the extracts we have given above from Professor Tait's work on "Recent Advances in Physical Science," we have only sought to present the recent ideas regarding the nature of atoms, without accepting them. Those who desire a more extensive acquaintance with this subject, and with the doctrine of the heterogeneity of matter, must consult Professor Tait's work.

CHAPTER III.

GENERAL PROPERTIES OF MATTER.

Indestructibility and transmigration of matter—Extensibility and impenetrability—Gravity and weight—Centre of gravity—Stability of position in animals—The balance—Weights and weighing—Essentials in a good balance—Method of double weighing—Density or specific gravity—Mobility—Inertia—Porosity—Compressibility—Elasticity—Divisibility.

31. Indestructibility and Transmigration of Matter.—We cannot create, neither can we destroy matter. The dew which has covered the petals of flowers with glistening drops, disappears when the rays of the rising sun envelop it. The water that formed it seems to have been destroyed, but it still exists. It has only passed from visible water to invisible vapor. Though the eye cannot perceive it, there is no difficulty in proving its existence by other means, and forcing it to reassume its visible liquid state.

The candle-flame by which we seek to extend the length of our days, offers even a better example of the indestructibility of matter. The wax or fat of which the candle is formed, is composed chiefly of carbon and hydrogen. In giving forth its light the flame slowly feeds upon the combustible substance, and as this wastes away, it appears to have been destroyed, but it has not. In the flame itself, through which we may rapidly pass the finger without feeling any resisting medium, there is solid matter. This we may easily show by causing a flame to impinge upon a cold surface, when at once it deposits soot or solid carbon. Even when the carbon has disappeared in the upper part of the flame, and only invisible products are present, we may, by passing these over melted potassium, recover the carbon in the same state as we found it in the flame. The carbon of the wax has not been destroyed, it has only changed its state so as no longer to be perceptible to certain senses.

Living plants and animals give an admirable illustration of the indestructibility of matter, and also of its unceasing passage through varied forms. The processes of animal life result largely in the production of carbonic acid gas, which is eliminated in the invisible state from the lungs. It is identical with the gas thrown off in the combustion in a candle-flame. It has even been said, and not without reason, that we ourselves may be likened

to flames. We are mere forms through which matter is passing. We consume food as the flame consumes fat, this in each case is oxidized, producing a more or less transient form. The product of the oxidation in both is the same, carbonic acid gas. To plants this gas, the refuse of the bodies of animals, is of the utmost importance. To them it is food and sustenance. They consume it with avidity. Out of it they construct their tissues, producing forms far more permanent than those of animals, but to be consumed by animals and again pass through the circuit of nature.

Matter, therefore, is not only indestructible, but certain kinds of it are ceaselessly passing through living creatures. Even man himself cannot claim as individual property the atoms which build up the organs of his body. They are not even the property of collective humanity, but have passed innumerable times through animal and plant creations. What a humiliating lesson this elementary scientific fact teaches us. The very bodies in which we take so much pride, and which we care for so tenderly, are merely passing forms of matter in which the spirit is clothed for a brief time. We die, and our corporeal particles escape us, never to be regained.

The ancient doctrine of transmigration we may reject when applied to the soul, about which we know nothing, but in the case of matter it is indubitable. Indeed, we may say that sufficient time being granted, it is as much a property of matter as indestructibility itself.

32. Extensibility and Impenetrability.—The first of these is *the property by which matter occupies a certain fixed portion of space.*

By impenetrability we understand that two portions of matter cannot occupy the same portion of space at the same time. If we press a bottle mouth downwards under water, the fluid cannot enter the vessel, since it is occupied by air. For the water to gain entrance the air must escape, as we see is the case when the bottle is immersed mouth upwards, when the rate of egress of the air is exactly proportional to the rate of ingress of the fluid. So, also, when a nail is driven into wood, the iron forces the wood to the right and left; the two bodies do not occupy the same space at the same time. Strictly speaking, the term impenetrability should only be applied to molecules and atoms. By some, extension and impenetrability are used as synonymous terms.

What has here been said applies equally in the case of so-called *penetrating wounds*, the term is not correctly used. *The tissues of the body are as impenetrable as any other matter, and the word is only admissible with the understanding that there is solution of continuity of the tissue.*

33. Gravity and Weight.—Matter may be dealt with under three conditions: molar, molecular, and atomic. The two forces of attraction and motion, which are inherent to matter, may also be considered from three similar points of view.

Atomic attractions and motions belong properly to the domain of chemistry.

Molecular attractions and motions determine the solid, liquid, or other form of a body, and its relations to light, heat, and electricity. Their consideration belongs to physics.

Molar attractions and motions are by many dismissed to the province of mechanics, but we have retained them within that of physics, of which mechanics may be regarded as a subdivision (5).

Molar attraction when applied to the attraction of the earth for objects on its surface, is called *gravity*. The resistance required to overcome this attraction is called *weight*, and is accepted as one of the properties of matter in general. For the determination of the weight of bodies, the student is referred to article 36, on the balance.

34. Centre of Gravity may also be called the centre of weight or attraction. It is the point in a body about which all its parts exactly balance one another. If this point be supported, the whole body will remain at rest in any position in which it may be placed. For many purposes the whole weight of a body may be regarded as being concentrated at its centre of gravity.

In bodies of regular geometrical forms, the centre of gravity coincides with the centre of form, and may be easily determined, provided they are of uniform density. In a circle or sphere, it is at the geometrical centre. In a cube, at the crossing of the diagonals. In a cylindrical rod or bar, such as may be used for the beam of a balance, it is at the centre of its axis.

The experimental determination of the centre of gravity of any irregular body, may be accomplished as follows: The body is first suspended by a string attached to one point, the line formed by the string is projected through the object. The point of attachment of the string is then changed, and the new line of suspension projected through the substance. The crossing of these two lines is the centre of gravity of the object.

The *stability of position* of a body depends upon the relations of its centre of gravity to its base. The essential condition is that the centre of gravity must lie vertically within the area occupied by the base. A greater extent of base, other things being equal, gives greater stability. The more vertical the centre of gravity over the centre of base, the greater the stability. The less the altitude of the body, the greater the stability.

The combination of all of these conditions gives the most

complete stability. A serious deficiency in any one of them may make the body exceedingly unstable, as when we attempt to stand a pyramid upon its apex. Though the centre of gravity may then be vertically over the centre of the supporting base, the latter is so minute that the slightest movement throws the centre of gravity to one side, or the other, of the supporting surface, and the body falls.

35. Stability of Position in Animals.—In quadrupeds, stability of position in the standing attitude is very great since their base of support is large, being represented by the area enclosed by their four feet, when in contact with the ground, and the centre of gravity is almost vertically over its centre. So little effort is required to maintain the erect position in these creatures, that they may often be seen sleeping in that attitude. Next in stability to quadrupeds, come the kangaroos. These, though biped in appearance, actually use the tail as a third leg, and so increase their base of support.

In bipeds like man, the base of support is so small that numerous trials are required before the power to keep the erect position is acquired. In the act of walking, by bending forwards, the centre of gravity is thrown first over one foot, and then over the other, as is imitated in the toy called the tumbler. According as the width of the pelvis is greater, the adjustment of the centre of gravity to the position of the feet requires greater extent of motion. Hence, the lateral sway seen in the walk of woman compared with that of man. The same movement is for a like reason exaggerated to a still greater extent in the waddling walk of the duck and goose.

The necessity of a continual adjustment of the centre of gravity to the supporting base, compels us to seek in surrounding objects some standard, by which we may ourselves maintain the vertical position. Vertigo and sickness often result when we are deprived of these standards of comparison. Hence, on shipboard, the continued departure of the objects in our vicinity from the perpendicular line, destroying the ordinary means of comparisons, we suffer from *sea-sickness*. The discomforts of this condition may often be avoided by lying flat on the back, and keeping the eyes tightly closed. Sea-sickness is also in part due to irregular pressure upon the internal organs produced by the motion, especially is this the case with the brain.

36. The Balance.—Of balances there are numerous forms. The ordinary balance consists of a rod of metal called the beam. This should be as nearly inflexible as possible. It is mounted as a lever of the first class, the fulcrum being a triangular prism passing through the beam, and so adjusted that it rests on one of

its edges. This is commonly called the knife-edge or axis of support.

The axis, in the finer kinds of balance, is supported on polished plates of agate to enable it to move with the least friction possible. Immediately beneath the knife-edge a long

FIG. 5.

Chemical balance.

needle is attached to the beam. It projects downwards, and by its oscillations over a graduated arc, enables us to measure with exactness the movements and position of the beam.

From the extremities of the beam the pans are suspended. In the finer kinds the method adopted is by knife-edges attached to the beam; on these agate surfaces rest which sustain the pans by means of slender wires of platinum.

When in use, the object which is to be weighed is placed in one pan; by its attraction for the earth, the pan in which it is placed sinks. Weights of known value are then placed in the opposite pan until the attraction of the earth for the object is overcome, and the beam of the balance assumes the horizontal position, or is equipoised, as is shown by the point of the attached needle oscillating to equal extents on the opposite sides of the zero of its scale.

37. Weights and Weighing.—The most convenient weights to be used in all medical or physiological investigations are the French. They possess the great advantage, first, of being decimal, and, second, they give the means of converting weight into volume, since *the cubic centimetre of distilled water at* 4° *C. weighs exactly one gramme, which is the unit of weight.*

In addition to the usual weights to be placed in the pan of the balance, there is a sliding weight, called the rider, which is placed on the beam of the balance, and which may be moved by means of a sliding rod which passes through the right side of the case of the instrument. The beam bears a graduation of ten parts; according as the rider is placed on one or the other of these, it measures one or more tenths of its own weight, which is usually one milligramme.

It is well always to use the same pan of the balance for the weights. The most convenient for the majority of persons will be the right-hand pan as one sits facing the balance. The sliding rod also is on this side. Substances to be weighed should never be placed directly in the pan of the balance, but a few thin watch-glasses should be procured. These should be numbered by diamond scratches on the glass, and the weight of each determined and recorded, or a counterpoise may be made for each. Either of these devices will save loss of time in weighing the watch-glass each time it is used.

When a weighing is to be executed, the balance should be tested by throwing it into action and seeing that the pointer vibrates equally on each side of the zero of the scale. Any change in the level of the base should be corrected by the screws and spirit-levels. The watch-glass should then be tested to see it has not lost any of its weight by accident. The substance is then placed in the watch-glass, and if a counterpoise is used the weight is obtained at once. If only the weight of the watch-glass is known, this is to be subtracted from the total weight of the substance and the glass, when the weight of the substance alone is obtained.

The weights should not be touched with the fingers, but the pincers in the weight-box should be used. To avoid error in reading the weights, they should be removed from the pan and placed in their order of value, either on the base of the balance or on the table, and counted up in that position before they are replaced in the weight-box. To the weight so obtained, the weight indicated by the rider should be added if it has been used.

Hygrometric bodies, or substances that absorb moisture from the air, should be placed in a watch-glass, the edges of which are ground fine and fit closely, air tight, to a flat ground-glass cover or to another watch-glass. The watch-glass and its contents should be placed in a hot-air box, and dried at 100°C. When it is judged that the exposure has been sufficient, the chamber should be opened, the watch-glass quickly covered and allowed to cool over sulphuric acid in the drying apparatus. It is then to be weighed and the weight recorded. The watch-glass is then uncovered and again exposed in the oven, twenty minutes or so; it is then quickly recovered, cooled, and re-

weighed. If the weight is the same as before, it is correct. If it has diminished, the operation of heating must be repeated until the substance ceases to lose weight.

In a few cases where heat is inadmissible, the drying must be done over sulphuric acid, with or without a vacuum. Light test-tubes closed by rubber stoppers are used sometimes in place of watch-glasses with covers.

38. Essentials in a Good Balance.—1st. The distances from the edge of suspension of the beam, to the edges of support of the pans on each side, should be exactly equal.

2d. When the pans are empty, the needle should point to the zero of its scale. The long axis of the beam is then in the horizontal position.

3d. When the beam is horizontal, its centre of gravity (34) should be vertically beneath the knife-edge of the fulcrum.

The sensitiveness of the balance, or its power to determine very small weights, or very small differences between two weights, depends upon three conditions:

1st. The longer the beam, the greater the delicacy of the balance, the length being measured between the points of suspension of the pans.

2d. The weight of the beam should be as small as is consistent with rigidity.

3d. The centre of gravity of the beam should be as near as possible to the edge of support and beneath it.

A good physical or chemical balance, when charged with 1000 grammes, or a kilogramme, in each pan, should indicate a difference of less than $\frac{1}{1000}$ of a gramme, or a milligramme, between the contents of its pans.

39. Method of Double Weighing.—Though a balance is not quite accurate, it may nevertheless be used for the exact determination of the weight of a substance by the above named device. The operation consists in putting the object in one pan, and then counterpoising it with shot and tinfoil in the opposite pan. The object is then removed from its pan and weights placed therein until the exact weight of the counterpoise is determined. This weight represents the weight of the object, since both it and the object have balanced the counterpoise, and are, therefore, equal.

40. Density or Specific Gravity.—A cubic inch of lead is almost forty times as heavy as a cubic inch of cork. As a rule, solids are heavier than liquids. To this there are notable exceptions. Organic and organized bodies generally float on the standard liquid, water. The metals potassium, sodium, and lithium, are

also lighter than water, lithium being but little more than half as heavy as that fluid. Mercury, on the contrary, presents us with a liquid form, on which all rocks and nearly all metals float. Iron drifts on its surface as readily as wood does on the surface of water.

A very good *definition of density or specific gravity is that it represents the weight of a given volume of a body compared with that of an equal volume of some other substance, taken as a standard.* In the case of solids and liquids, water is the standard. If to it the value 1 is given, then the specific gravity of platinum, which is about twenty-two times as heavy, becomes 22. In like manner, the unit of specific gravity for gases and vapors is either air or hydrogen.

41. Mobility.—*Mobility is that property of matter by virtue of which its position may be changed.*

Motion and rest may be either absolute or relative. They are absolute when the change or fixity of the position of a body is referred to ideal fixed points in space. They are relative when referred to surrounding bodies. A passenger on a steamer may be relatively at rest as regards the boat and the objects thereon, but he is in a state of relative motion as regards the banks of the river. These, in their turn, may be relatively at rest as regards the earth itself, but in motion when considered in relation to other planets and stars. For practical purposes we may, therefore, say, that absolute rest and motion are unknown, we deal with rest and motion only in their relative state.

42. Inertia.—*By this we understand that matter cannot of itself change its condition either of rest or motion.* If at rest, it remains so until some force acts upon it to produce movement. If in motion, it continues to move until some force causes the movement to cease.

When we release our grasp on any object it falls to the earth. The movement is not by virtue of any inherent property of the substance, but because it is acted upon by the force of gravity. A rifle-bullet finally comes to rest, not by virtue of its own powers, but on account of the resistance of the air and other causes. If there were no such counteracting forces, it would continue to move forward at the same rate forever.

Examples of inertia of motion are offered by a careless descent from a moving vehicle: our feet strike the ground and cease to move, while the movement of the upper part of the body continues, and we are thrown prostrate. The fearful accidents on railways are due to this cause. The motion of the engine being suddenly checked, the cars continue their advance,

and are shattered by the force with which they are driven into each other.

The following simple experiments on inertia of rest are not without interest. If we place a card upon a goblet, and then rest a coin upon the card, we may, by a sudden fillip of the finger, cause the card to glide off the tumbler. The coin does not pass with it, but, detained by its inertia, drops into the vessel, drawn down by gravitation. Gentle pressure against a suspended sheet of glass will cause it to move, while if a pistol be fired at it from a sufficient distance the bullet passes through the glass without producing the slightest change of position in the latter.

43. Porosity.—The interstices or spaces between the parts of a substance are of two kinds. 1st. *Physical pores*, which exist between the molecules, and are so minute that the molecular forces of attraction or repulsion act across them. 2d. *Sensible pores*, cells or cavities across which these forces cannot act, on account of their magnitude. The effects of temperature in causing variations in the size of bodies are possible by virtue of the existence of physical pores or interstices (19, 20). In organic substances the sensible pores are of especial importance, since they permit the functions of absorption, exhalation, and circulation.

The existence of sensible pores in organic bodies may be illustrated by placing them in a vessel of water under an air-pump bell. An apple or a potato thus treated yields up innumerable bubbles of air or gas, which escape from the cells or pores of the fruit or tuber. If the weight of the object of the experiment be taken before and after exhaustion, the increase in weight will show the extent or volume of the pores, since it represents the quantity of water which has replaced the air contained in them.

In sponge, and in pumice, the sensible pores are of considerable size and easily visible. In metals, on the contrary, they are very minute. Gold, for example, was shown by the Florentine academicians to possess pores, in the following way: They were attempting to determine the compressibility of water. For this purpose the fluid had been enclosed in a sphere of gold, which was hermetically sealed. The sphere was then submitted to pressure; any change in shape they knew would be attended by diminution in its capacity. Their surprise may be imagined when, on applying the force, minute globules of water were seen to ooze from the metal, and cover its surface with dewy drops. As is so often the case, the experiment, instituted to determine one fact, resulted in the unexpected establishment of another and totally different one. The same ex-

periment has since been repeated with globes of other metals, and the existence of minute sensible pores demonstrated.

Among the practical applications of sensible pores, we may mention the process of filtration through felt, paper, charcoal, and stone, so commonly employed for the purification of water. The opening of seams in rocks, by introducing dry wedges of wood and then wetting them, when they expand with great force, furnishes another example of the existence of pores.

44. Compressibility is a direct consequence and demonstration of porosity.

The most compressible bodies are gases, some of which may be forced to diminish to one hundredth of the bulk they present at ordinary temperatures and pressures. To this there is, however, a limit in every case, for under sufficient pressure and reduction of temperature, gases assume the liquid state.

Solids in many cases are compressible to a moderate extent. This is best shown by organic substances, as wood and paper. Metals also, when submitted to the pressure of the die in coining, or when hammered, undergo an increase in specific gravity, which can only be explained by the diminution in the size of their pores, and consequent diminution in volume.

In the case of liquids the compressibility is the least for small pressures, and was for a long time denied. It however exists, as will be shown when we study the properties of this form of matter.

45. Elasticity *is the property by which certain bodies reassume their original volume or form, when the force that has produced change is removed.*

Gases and liquids are endowed with this property, as regards volume, to a remarkable degree. They may indeed be said to be absolutely elastic (163). Solids, as we have seen, are very generally compressible, but a few, like ivory, possess a certain degree of elasticity. The elasticity of solids is rather that of form than of volume, and belongs to the consideration of the properties of this special kind of matter (67).

46. Divisibility, we have already dealt with in the examination of the structure of matter (22), to which the reader is referred.

SECTION II.

SOLID MATTER.

CHAPTER IV.

GENERAL CHARACTERS OF SOLIDS.

The physical forms of matter—Chemical divisions of matter—Form is fixed—Resist compression—Extent of volume variation—Density—Hydrostatic balance—Specific gravity by volumetric method—Nicholson's hydrometer—Specific gravity of powders—Specific gravity of bodies soluble in water—Bodies lighter than water—Table of specific gravities—A divided solid does not reunite.

47. The Physical Forms of Matter.—Physicists classify matter under three typical forms: 1st, Solid; 2d, Liquid; 3d, Gas. Some add a 4th, Radiant or ultra gaseous.

It is to be understood that by proper means these forms may be transmuted one into another. The terms are applicable to each substance only under the ordinary conditions of temperature and pressure.

The demarcations between these forms are not always clean cut. Certain liquids, for example, pass through an intermediate or pasty condition before they become solid; others are gelatinous, others viscous.

Intermediate between liquids and gases, we find a group of bodies called vapors, which closely resemble gases, except that they are easily convertible into liquids. In all probability there is a continued gradation, from the densest solid to the most rarefied form of gaseous matter.

48. The Chemical Divisions of Matter.—These are three in number: 1st, Inorganic bodies; 2d, Organic; and, 3d, Organized. A knowledge of the general characters of these groups is necessary for the proper comprehension of our subject.

The *inorganic* group includes all the ordinary objects on the globe which have not been dependent upon life action in

plants or animals for their production. Minerals of all kinds, and ores, water, and air, are typical examples of this division. Certain bodies, as marble, chalk, graphite, have been produced through the intervention of life action, yet they are truly inorganic substances; others, on the contrary, like bituminous coal, may be grouped with organic substances, since, on being distilled, they yield oily bodies which are organic in their nature. The type of visible structure among inorganic bodies is the crystalline, many are non-crystalline or amorphous, while a few, like wrought iron, are fibrous.

Organic and organized bodies are all compounds of carbon. So absolute is this fact that their study is often spoken of as the study of the carbon compounds. Next to carbon are present, hydrogen, oxygen and nitrogen, the order of frequency being the same as that in which they are mentioned. All substances of these groups are decomposed by a heat less than 1000° F. If heated in vessels to which air does not gain free access, a black residue of charcoal or carbon is left, which may be entirely burned away in a current of air.

Organic differ from organized bodies in that they are generally crystalline in structure. Though commonly the product of life action—*e. g.*, sugar—many of them have been made in the laboratory by the union of the elements themselves, without the intervention of any life action. Acetyline, for example, is produced by the passage of the electric arc between poles of pure carbon in an atmosphere of pure hydrogen. From acetyline alcohol may be made, and from alcohol fatty bodies which are truly organic in their nature. Every day adds to the list of organic bodies produced by purely chemical processes, and doubtless the majority of these substances will in time be prepared artificially.

Organized bodies, on the contrary, have never yet been produced by process into which life action does not enter, and we may safely say that they never will be. They differ from simple organic bodies, in that their structure always shows the presence either of the cell or of the fibre. They are not crystalline, though they may enclose crystals of organic or inorganic bodies.

49. The Form of Solids is Fixed.—True solids have a permanent and independent form. In this respect they differ essentially from liquids and gases, which take the form of the vessel in which they are placed. In certain resinous bodies this quality is possessed only in a low degree, these substances slowly changing their form in the lapse of time. Among the true solids some show more or less of plasticity; for example, ice. It is the possession of this character which enables a glacier to follow the curves and windings of the valley through which it descends.

Prof. Tyndall attributes the plasticity in this case to alternate fusions and freezings of the ice, to which he has given the name of regelation.

50. Resist Compression.—True solids resist any ordinary force of compression to which they may be subjected. While some possess this power to only a slight degree, others possess it to a remarkable extent. All at last, however, reach their limit of resistance. Some, like quartz and glass, are crushed, while others, as the metals, undergo an actual diminution in bulk.

51. Extent of Volume Variations.—While changes of temperature and of pressure produce variations in the volume of a solid, these are exceedingly minute, compared with similar changes in liquids and gases. Of this fact we have seen an example in the case of the experiment (19), in which very delicate means were required to determine the expansion of the mass of metal.

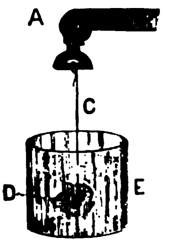
52. Density of Solids.—To obtain the specific gravity of a solid, as urinary or biliary calculi or a urinary sediment, we must know its weight in air, and the weight of an equal volume of water. *The first is then divided by the second, when the quotient is the specific gravity.*

The conditions under which the determinations of specific gravity are to be made vary as follows:

1. Solids heavier than water and insoluble therein.
2. Powders heavier than water and insoluble therein.
3. Solids heavier than water and soluble therein.
4. Solids lighter than water and insoluble therein.
5. Solids lighter than water and soluble therein.

By the *principle of Archimedes*, a body immersed in water displaces its own volume of that liquid, and at the same time loses a part of its weight equal to the same bulk of water. Our object being to determine the weight of a volume of water equal to the bulk of the substance, we may, by applying the principle stated above, obtain it at once by weighing the body in water, when the loss of weight will be the weight of an equal volume of water. This is the ordinary process, and is called the method by the hydrostatic balance.

FIG. 6.



Hydrostatic balance.

53. The Hydrostatic Balance.—The application of this process to the *first condition given above* is as follows: The object (D) is suspended by a fine fibre (C) to one arm (A) of a balance. Weights are placed in the opposite pan. The weight in air is thus obtained: A vessel

of water (E) is then placed beneath the suspended object, and raised until the object is completely immersed in the fluid. The weight is again determined; it is the weight in water. The weight in water being subtracted from the weight in air, we have the weight of a bulk of water equal to that of the object, for example:

Weight in air	= 10	
Weight in water	= 8	
Loss of weight in water	= 2	is weight of equal bulk of water.

Then by (52),

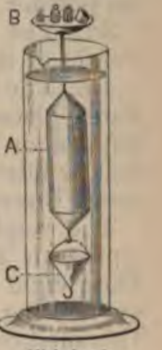
Weight of equal bulk, water 2) 10 = weight in air
5 = specific gravity.

54. Specific Gravity by Volumetric Method.—A second method for obtaining the specific gravity *under the first condition* is that by *volume*. It is well adapted to many medical purposes, and though not so accurate as the preceding, gives proximative results that are sufficiently exact for ordinary use.

The apparatus to be employed consists of a tube graduated to cubic centimetres. This is partially filled with distilled water, each division of the scale then represents one gramme of water.

The solid to be examined may be either in mass or in small fragments. Its weight in air in grammes is first obtained. It is then dropped into the liquid in the tube and all bubbles of air removed from its surface. The amount of water displaced is shown by the rise of the fluid on the scale. This is read off, and gives at once the weight in grammes of a volume of water equal to that of the substance. The weight of the body in air and that of an equal volume of water being known, the specific gravity is obtained by the usual calculation.

Fig. 7.



Nicholson's hydrometer.

55. Nicholson's Hydrometer.—Another method for the determination of specific gravity of solids, is by means of Nicholson's hydrometer.

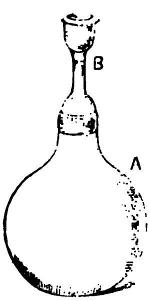
This instrument consists of a hollow metallic float A which bears a weight-pan above at B, and another below at C. The apparatus is placed in water, and weights added to the upper pan B to sink the cylinder to a mark on its stem. Let this be 120 grains. It is removed and a mass of the substance less than 120 grains in weight placed thereon. Weights are then added until the water touches the mark on the stem of the apparatus. Suppose 20 grains have been added, this subtracted from 120 grains gives the

weight of the body as 100 grains, which is the weight of the body in air. The substance is now transferred to the lower pan C. The cylinder does not sink as deeply in the water as before. More weight must be placed in the upper pan to bring the mark to the level of the water. Suppose the weight now added to the upper pan is 50 grains, this represents the weight of the water displaced by the object. Then dividing 100, the weight in air, by 50, the weight of equal volume of water, we have the specific gravity.

If the body is lighter than water, it is confined to the lower pan by a wire cage.

56. Specific Gravity of Powders.—In the second condition, of *powders heavier than water and insoluble therein*, the method is as follows: A specific gravity flask (A) with a wide mouth is to be used. The stopper is perforated and gives passage to a narrow tube which expands above into a larger one. A counterpoise for the flask should be made and kept in the opposite pan throughout the operation. The flask should always be filled to a certain mark (B) when a liquid is used. The excess of fluid which rises into the upper tube above this point should be removed by blotting paper. The steps of the operation are as follows:

FIG. 8.



Specific gravity flask.

1st. The quantity of distilled water at 4° C. the counterpoised flask will hold when the perforated stopper is in position and filled to the mark is determined.

2d. The flask is carefully dried, some of the dry powder is introduced, the stopper placed in position, and the weight of the powder introduced determined.

3d. The weight of the water the flask will hold and the weight of the powder are added together. Let this be w.

4th. The flask containing the powder is then half filled with water, placed under an air-pump bell and exhausted. The entrapped air is thus removed, the powder is allowed to settle, the flask is filled completely, the stopper introduced, excess of fluid above B removed, and the weight determined. Let this be v.

The weight v is then subtracted from the weight w, the result represents the weight of the water the powder has displaced. The weight of the powder and the weight of an equal volume of water being known, the specific gravity is calculated as before. This method is employed in the determination of specific gravity of uric acid and other insoluble sediments.

57. Specific Gravity of Bodies Soluble in Water.—To *meet the third condition, in which the body is soluble in water*, some other fluid, as

oil of turpentine, or naphtha, in which it is insoluble is substituted. The correct specific gravity is then obtained by multiplying the number found by the specific gravity of the fluid used in the experiment. All the preceding steps are conducted as before.

58. Bodies Lighter than Water.—For the fourth condition, *body lighter than water, but insoluble*, the steps are as follows:

1st. Ascertain weight of substance, is *A*.

2d. Determine weight in water of a piece of lead heavy enough to sink it, is *B*.

3d. Attach light body to the piece of lead and determine the conjoined weight in water, is *C*.

4th. Deduct *C* from *B* and add *A*, this is *D*.

5th. Divide *A* by *D*, and the result is the specific gravity of *A*.

The fifth condition, *body lighter than water and soluble therein*. The specific gravity flask is to be employed, and benzine substituted for water. The steps are the same as before described for the flask operation. The weight of a bulk of water equal to that of the displaced benzine is obtained by the following equation: As specific gravity of benzine is to the weight of benzine displaced, so is the specific gravity of water to the weight of volume of water equivalent to that of the body.

Weight of substance and weight of equivalent volume of water being obtained, density is calculated as before.

59. Table of Specific Gravities.—*Specific gravity of solids as compared with distilled water at 4° C.*

Platinum, rolled	22.069	China porcelain	2.385
Platinum, cast	20.337	Sevres porcelain	2.146
Gold, stamped	19.362	Native sulphur	2.033
Gold, cast	19.258	Bone	2.010
Lead, cast	11.352	Ivory	1.917
Silver, cast	10.474	Anthracite	1.800
Bismuth, cast	9.822	Compact coal	1.329
Copper, drawn wire	8.878	Muscle	1.085
Copper, cast	8.788	Amber	1.078
German silver	8.432	Soft organs of body	1.050
Brass	8.383	Brain	1.040
Steel, not hammered	7.816	Sodium	0.970
Iron, bar	7.788	Lung with air	0.940
Iron, cast	7.207	Melting ice	0.930
Tin, cast	7.291	Fat	0.920
Zinc, cast	6.861	Solid ice	0.917
Antimony, cast	6.712	Potassium	0.865
Iodine	4.950	Beech	0.852
Heavy-spar	4.430	Oak	0.845
Diamonds	3.531–3.501	Elm	0.800
Flint glass	3.329	Yellow pine	0.657
Statuary marble	2.837	Lithium	0.585
Aluminium	2.680	Common poplar	0.389
Rock crystal	2.653	Cork	0.240
St. Gobin glass	2.488		

60. A Divided Solid does not Reunite.—If a gas or a liquid be divided by any object passing through it, it reunites immediately behind the dividing body. In solids this, as a rule, is not the case. There are, however, a few exceptions: India-rubber will reunite by its freshly cut surfaces. Some of the metals will also reunite behind a cutting tool if they are at the same time submitted to very great compression.

CHAPTER V.

SPECIAL PROPERTIES OF SOLIDS.

Crystallized and amorphous—Hardness—Fragility—Malleability—Ductility—Tenacity—Elasticity—Contractility—Elasticity of compression—Elasticity of flexure—Elasticity of torsion—Pliancy—Opacity, transparency, color—Building materials—Hypothetical consitution of solids.

61. Crystallizable and Amorphous.—*The cohesive or attractive force by which the molecules of a solid are held in their place, is not always equal in all directions around each molecule, but is greatest in certain positions, lines, or planes*, as is the case with the poles of a magnet. When the molecules of such a body are free to move, they arrange themselves in relation to these lines or planes, and produce more or less perfect forms called crystals. Substances which do not possess this property are called non-crystalline or *amorphous*.

Crystallization of a solid may take place in two ways. 1st, From the fused or melted body, as in the case of bismuth. This is called crystallization in the *dry way*. 2d, From a solution of the substance in water or some other solvent liquid. This is called the *moist way*.

Water in the act of solidification presents a beautiful example of crystallization. The moisture which on a cold day congeals on the pavement or on windows, presents varied forms, closely resembling the leaves and stems of ferns and other low varieties of vegetation. One can hardly give these frostings a passing glance without suspecting that the outlines of inferior plants are determined by the simple act of the passage of water from the fluid to a more or less fixed condition of solidity.

Under the microscope the formation of crystals of inorganic and organic bodies from their saturated solutions, presents

most interesting phenomena. We may in this way detect the presence of numerous substances on a very minute scale. As an illustration of this method, we may cite the example of urea, an exceedingly soluble body with so great an avidity for water that it will absorb it from the air, and deliquesce or form a solution. If to a drop of such a solution, placed on a microscope slide, we add a drop of nitric acid, the nitrate of urea forms. This being but little soluble in water crystallizes out, and by the appearance of the peculiar table-like crystals, we are at once informed of the presence of urea in the liquid under examination.

The satisfactory demonstration of the crystalline structure of a solid soluble in water may be obtained by placing a portion of it in a saturated solution thereof. Under these conditions the dissolution takes place very slowly, and the crystals composing the body are dissected out from the mass. Under this method of operation alum may be made to exhibit its structure of regular octahedrons. Experiments of this nature show that the resistance to solution is strongest along the crystalline planes.

In like manner, if we attempt to split a crystalline body by means of a point or an edge, as we would split wood, we find that it yields with comparative ease along certain planes which give smooth surfaces of fracture, whereas it cannot be split, but only broken along other planes, the fracture showing rough in place of smooth surfaces. This splitting along certain planes in preference to others is called *cleavage*. It is exhibited in greater or less perfection by all inorganic and organic crystalline bodies.

In the examination of the deposits which appear both in healthy and morbid urine, a knowledge of the crystalline forms presented by various normal and abnormal ingredients of this complex fluid are of the utmost importance for the purposes of diagnosis. A few moments spent in the careful microscopic examination of such sediments, and the detection of certain crystalline forms, will at once throw a flood of light on what may otherwise be a very obscure and puzzling disease.

The detection of the presence of poisons also may be greatly facilitated by a microscopic examination of the crystals obtained from the solutions administered, and sometimes even of the secretions and excretions of the body. For an admirable discussion of this, the micro-chemistry of poisons, the student is referred to the excellent work of Prof. Theo. G. Wormley, M.D.

Mention has been incidentally made of the fact that certain organic bodies assume a crystalline form, while others do not. Bodies which are of the crystalline type, possess the property of passing with considerable facility through membranous structures of various kinds. Those which do not crystallize, as, for

example, albumen, possess this property of permeating membranes to a far less degree. Hence arises the division of bodies into the two groups, *crystalloids and colloids*. This will be found discussed at greater length in the article on dialysis.

62. **Hardness** is a relative property. *By it we understand the resistance which one body presents to being abraded, worn, or scratched* by another. It is entirely independent of density. Pure gold, for example, is one of the heaviest metals, but it is very soft. The true cause of hardness appears to be the force with which the molecules resist any change in their polar or crystalline arrangement.

For the purposes of the mineralogist, a scale of different degrees of hardness, known as *Mohr's scale*, is used. It consists of the following ten substances, each member of the list being harder than that preceding it:

1. Talc.	6. Adularia feldspar.
2. Rock-salt.	7. Rock-crystal.
3. Calc-spar.	8. Prismatic topaz.
4. Fluor-spar.	9. Corundum.
5. Apatite.	10. Diamond.

To test the hardness of a body, we determine which of these it will scratch, beginning with the hardest. If it is scratched by topaz, but scratches quartz or rock-crystal, we say its hardness is between 7 and 8.

Alloys, as a rule, are harder than the metals composing them; therefore, in the mints gold and silver are alloyed with copper to give them sufficient hardness to resist the wear and tear of circulation. The resulting coin is far harder than either of the metals in the pure state.

There is no relation between the hardness of a body and its power to resist compression. A blow which shivers hard glass is easily resisted by soft wood. Hardness is also often independent of the chemical composition of a body. Carbon, for example, in the form of the diamond is the hardest substance known; in the form of graphite, on the contrary, it is so soft that it is easily cut by the thumb-nail, and it is even used as an antifriction or lubricator for the journals and axles of wheels.

When certain bodies, like steel, are raised to a specified temperature and then suddenly chilled, they are endowed with exceeding hardness. This operation is called *tempering*. Upon it all our surgical and other cutting implements of steel depend for their power to retain their sharpness or edge. In the case of an alloy of copper and tin, called *tamtam* metal, sudden chill-

ing in water produces exactly the opposite effect, the *alloy* being soft when quickly, and very hard when slowly cooled.

We have thus far considered the question of hardness in relation to inorganic bodies alone. We have seen that the mineralogist employs a scale of tolerable exactness to determine the relative hardness of the bodies with which he deals. It is surprising that, with this example before him, the physiologist and pathologist have not yet contrived a scale by which this factor of the properties of the bodies they examine might be expressed with some approach to accuracy and fairness of comparison.

While the hardness of enamel, dentine, bone, and horn, as in the finger-nail, may be expressed by Mohr's table, that of various tissues and of tumors like cancer, falls outside of its limits. A table of hardness constructed on a scale prepared by a known mixture of resin, wax, and oil in ten different proportions, and used always at 32° F., or in a mixture of ice and water, would doubtless give results regarding the hardness of various tissues and tumors, which would be of considerable importance from a diagnostic point of view.

63. Fragility.—*Though allied to hardness, fragility is distinct therefrom.* It is true that, as a rule, very hard bodies are also brittle or fragile. The molecular conditions that produce hardness, also conduce to fragility. Sudden changes of temperature are very apt to cause a substance to become fragile. Glass, for example, if suddenly chilled, as in the formation of Rupert's drops, is marvellously brittle. The fracture of a portion of the tail of these tadpole-shaped objects, immediately causes the body to fly into thousands of pieces. Even in the ordinary state glass is too brittle for common use, unless it has been reheated and very slowly cooled. Such an operation is called *annealing.* It often requires many days for its successful completion. If proper care is taken in this operation, the glass may have its brittleness so reduced as to bear very rough usage. It may even be dropped from a height on to the floor, or submitted to the blows of a hammer. In this condition it is known as *malleable glass.* In its malleable state the glass differs but little from a Rupert drop in hardness, while the difference in fragility or brittleness is very great.

Among organized bodies like bone, variations in fragility are frequently seen. In this case, however, the change is owing to alteration in chemical composition or proportion of the ingredients entering into the structure of the substance.

64. Malleability *is the property by which certain bodies may be beaten or rolled into exceedingly thin leaves.* In these substances the molecules appear to have no particular lines of coherence, but

to suffer themselves to be pressed or forced out of their position in all directions with equal facility. In this respect they resemble the particles of a liquid.

Of all metals, gold is the most malleable. It may be beaten into leaves $\frac{1}{300000}$th of an inch thick. In this state of tenuity, the metal allows a bluish-green light to pass through it. Tin also is quite malleable, and may be made into leaves the $\frac{1}{1600}$th part of an inch thick. It is by virtue of this property of malleability that the coppersmith produces from flat sheets of copper, various hollow domestic utensils, as kettles, without a single seam or crack throughout their whole extent.

Of the ordinary malleable metals two, viz., platinum and iron, possess the property of being *welded*, or united together at a white or red heat. By the discovery of this *welding property* in the case of platinum, a distinguished English chemist is said to have made an enormous fortune by his own hands. He bought platinum black and scrap metal, and raising it to a white heat submitted it to blows in a steel cylinder, and thus converted it into bars or ingots, thereby more than quadrupling its value. The welding property of gold at the ordinary temperature of the air is applied by the dentist in filling teeth.

65. Ductility.—Allied to malleability, but differing therefrom, *is that property possessed by some metals which enables us to draw them out into wires of marvellous fineness.*

A platinum wire only the $\frac{1}{30000}$th of an inch in diameter, was made by Dr. Wollaston in the following way: A wire of platinum was placed in the interior of a silver cylinder; the compound bar was then drawn out in the usual way, until the limit of ductility was reached. The silver was then dissolved in nitric acid, when a platinum wire remained, which was about half the thickness of the thread of a spider's web, and only distinctly visible when heated to redness in a flame.

Next to platinum, the order of ductility for the metals is silver, iron, copper, gold. Molten glass is also very ductile.

Certain organic bodies rival and even surpass inorganic substances in this respect. Sugar, for example, may, at certain temperatures, be drawn into threads far finer than the wires of many metals.

Of all known bodies, that which possesses this property in the highest degree is the liquid silk from which the spider spins its gossamer thread. Near the extremity of the abdomen in these creatures, there are four to six nipples, each of which, in some species, is perforated by about a thousand minute holes. From these the adhesive fluid oozes to form the thread, which hardens on contact with the air. The final thread of the web,

fine as it is, therefore, contains innumerable minute threads which have issued from the apertures of the spinneret.

66. Tenacity is defined by Ganot as "*the resistance which a body offers to the total separation of its parts.*" It differs according to the manner of application of the force. In the ordinary sense it is resistance to traction, or a pulling force. If applied to resistance to fracture, it is called *relative;* to resistance to crushing, *reactive;* to resistance to lateral displacement, *sheering;* to resistance to twisting, *torsional.*

Continued application of a force diminishes the tenacity of a wire; elevation of temperature has the same effect. Tenacity also varies with the form of the bar; it is greater in a cylinder than in a prism, and greater in a hollow than in a solid cylinder. In the latter case it reaches its maximum, when the external radius is to the internal as 11 to 5. The tenacity of many bodies is greater in one direction than in another. Wood, for example, offers greater resistance with the grain than across it.

Animal and vegetable structures offer numerous examples of the use of hollow cylinders to increase tenacity. The quills of bird feathers, the bones of animals, and the stems of grain, are all constructed on this plan. The fibre of the silk-worm has a tenacity equal to that of brass wire, and three or four times that of a hemp fibre of equal diameter. Ligaments and tendons are very tenacious. Catguts made of intestines of the sheep and goat, also possess great tenacity.

The superiority, in this respect, of iron and steel over other substances is shown by the following table, in which the weight in tons, supported by a rod one inch square in section, is given.

Metals.

Cast steel	45–60 tons.	Silver	5 tons.
Wrought iron	25–30 "	Gold	4½ "
Cast iron	6–13 "	Zinc	2 "
Copper	9–26 "	Tin	1½ "
Platinum	8 "	Lead	1 "

Woods.

Teak	7–9½ tons.	Deal	6 tons.
Oak	4–9 "	Beech	5 "
Ash	8 "		

67. Elasticity, in general terms, may be defined as *the property by virtue of which a body that has been changed by the action of force regains its original form and size when the force is relaxed.* In liquids and gases the term is applicable only to variations in volume; in solids it applies also to the position of the molecules.

Both hard and soft solids are endowed with elasticity. In the former the extent of strain permissible within the limits of

elasticity is much less than in the latter. If the *limit of elasticity* is exceeded, a permanent set is produced, as, for example, when the ligaments of a joint are sprained.

As was the case with tenacity, elasticity in solids presents itself under different aspects, viz.: 1st, of traction; 2d, of compression; 3d, of flexure or bending; 4th, of torsion or twisting. In ordinary parlance, elasticity of *tension or traction* is applied to bodies like India-rubber, which will undergo considerable elongation without breaking. In such cases the return to the original length is only partial, and after they have been stretched a few times they show a permanent elongation. The true force of elasticity in solids in scientific signification, is not so much that property which permits extension as it is that which permits the displaced molecules to return to their original position.

Among animal tissues, examples of elasticity of traction are offered by the yellow elastic tissue in the arteries and by the ligamentum nuchæ. It is said that in the long neck of the giraffe, if the ligamentum nuchæ be cut from its attachments to the vertebræ, it cannot again be stretched to its original length without rupture, so great is the force with which it has contracted upon itself.

68. Contractility.—The power of contractility, *whereby a muscle under the influence of nervous stimulus can increase or diminish its own length, is the highest development of elasticity of traction.* The force with which a muscle contracts is not realized until we examine the manner in which it is attached to the bones upon which it acts. Invariably it works on the short arm of a lever, and, therefore, to produce results which appear to be feeble, very great contractile force must be developed.

While acting under the control of the will, the contractions of a muscle are usually within the limits of its elasticity, occasionally, however, where supreme efforts have been made the limit of elasticity is overpassed, and rupture takes place. This not unfrequently happens in the contractions attending certain spasmodic diseases, and also from the action of drugs like strychnia.

Though docile and obedient to the nervous influence while a creature lives, the muscular tissue asserts itself after death, and makes its last and most prolonged effort of contraction, thereby producing the condition of the body called *rigor mortis.* This usually supervenes in from three to six hours after death, but it often comes on much sooner. Nurses always bind the jaw and close the eyelids as soon as possible after death, experience having taught them that sometimes the rigor sets in in these parts within a few minutes. Brown-Séquard says that rigor mortis sometimes comes on before the heart has ceased to beat.

In death on the battle-field, when a bullet has struck a vital

part and death is almost instantaneous, rigor mortis occurs immediately. The hand grasps the rifle with a firmer grip than in life, and the last expression of fury, or of terror, that flitted over the face, is stamped on the marbled countenance of the dead soldier.

Duration of rigor mortis depends largely on temperature among other causes. Sometimes it lasts only one or two hours. In winter it often endures for six or eight days; in very cold weather, even for two or three weeks.

The slaughtering of animals for table use should always be so managed as to allow time for the rigor mortis to pass off. From an æsthetic point of view, it is not pleasant to dine off a chicken we have just seen disporting itself on the lawn of our friend's country seat. From an epicurean point of view, such flesh is always tough.

69. Elasticity of Compression.—An admirable example of the *elasticity of compression is offered by an ivory billiard ball.* If such a ball be dropped from a height upon a smooth stone slab which has been smeared with black paint, the paint will form a spot of considerable diameter upon the ball. Resting the ball on the surface of the slab, only a minute spot is formed. It is therefore evident that when the ball strikes the surface with considerable force its particles are driven in, or, in other words, it undergoes compression, otherwise the formation of the large spot is inexplicable. It is the instant return of the molecules of ivory to their original position that causes the ball to rebound from the slab. This property is possessed in so high a degree by ivory that long-continued use of balls made of this substance produces no appreciable change in their spherical shape.

This form of elasticity is exemplified in animals by the intervertebral substance.

70. Elasticity of Flexure.—*When a horizontal bar of metal or wood is fixed at one extremity, and a weight applied at the other, the rod flexes or bends.* The moment it is released from the weight it springs back toward its first position, passes it, and after a greater or less number of oscillations, it comes to rest at its original position. This is what is meant by elasticity of flexure. It is of interest in connection with the phenomena of sound, as produced from tuning-forks and other acoustic apparatus. These are to be the subject of study hereafter. This form of elasticity in metals is generally increased by chilling or hardening, and lessened by annealing. Some metals, as steel, possess it in a high degree, in others it scarcely exists. It is of importance in the construction of all forms of surgical apparatus in

which springs are used, as in the trusses for hernia and appliances for the correction of deformity.

Among organic bodies, it is seen in the costal cartilages; wood, likewise, possesses elasticity of flexure in a high degree. It is also found in such substances as feathers, wool, and hair, and gives to them the elasticity which adapts them for use in the construction of pillows or cushions, and other articles of furniture.

The elastic virtue in hair has rendered its use possible as a means for the commission of murder. Instances are on record in which very finely chopped hair has been mixed with food and administered to the victims of the poisoner. Under the contractions of the stomach the portions of hair, by alternately yielding and regaining their form by virtue of their elasticity, have worked their way into and become imbedded in the mucous and muscular coats of the organ, to such an extent as to become sources of local inflammation which has finally caused death. The obscurity of origin, and the natural characters of inflammation so produced, render the detection of the crime exceedingly difficult.

71. Elasticity of Torsion *is that property by which, when a suspended rod, wire, or fibre is fixed at the upper end and twisted at the lower, the free end returns immediately towards its original position when released from the twisting force.* If a shot, or other heavy body, be attached to the lower end of the suspended wire, in untwisting, the wire passes beyond its original position, and then returns in the opposite direction. Thus a series of oscillations are produced. An apparatus formed on this principle, and known as the *balance of Coulomb*, is used for the measurement of electric attraction and repulsion.

Spiral springs involve elasticity of torsion in their action as well as other kinds of elasticity. In certain kinds of plants, such spiral elastic springs are applied to the purposes of projecting the seeds to a distance from the parent plant. The castor-oil plant can in this way throw its seeds to a distance of ten or fifteen feet. Elasticity of torsion is possessed in a high degree by wood and steel; scarcely at all by lead.

72. Pliancy.—*By this we mean the property of being suddenly bent and twisted without fracture*, as in the making of cord from hemp or cotton.

Organized bodies being commonly more or less fibrous in their structure, possess this property, which is very rarely found among minerals.

Cotton, wool, flax, silk, hair, and all similar materials which are woven into cloth or fabrics, are exceedingly pliant. It may be said to be the chief cause of their value.

Among minerals an exceptional example of pliancy is found n the substance called *asbestos* or *amianthus*. So flexible is sbestos that it has been woven into gloves, jackets, and other rticles of clothing. Since amianthus resists the action of very igh temperature, such articles of clothing are incombustible. The difficulty connected with their practical use, is that they re so heavy that if a fireman dressed in a suit of *asbestos cloth* appens to fall, it is almost impossible for him to rise again.

73. **Opacity, Transparency, Color**, are important properties of solid as well as other forms of matter. The study of these is best accomplished in connection with the examination of the relations of light to such bodies.

74. **Building Materials.**—These embody many of the properties of solids which we have just examined. The occurrence of accidents whereby life may be destroyed or persons maimed, renders it desirable that the physician should have some knowledge regarding the changes to which these materials are liable.

Wood, and similar organic bodies, undergo a gradual change in the nature of a slow oxidation, which Liebig has called *eremacausis*. This destroys its fibrous and cellular character, and undermines its strength. The stability of wooden structures is, therefore, of comparatively brief duration.

In the construction of railways, the preservation of the wooden ties on which the rails are laid is of the utmost importance. Exposed as they are to the action of weather, they are very prone to this destructive change. To prevent it the wood has been injected with various solutions, as chloride of zinc, carbolic acid, tar, and others too numerous to mention. The best method for injection seems to be to draw the solution into the wood by exhaustion, rather than to force it in by pressure.

Iron, now so commonly employed in construction of buildings and of railways, under the continued vibration and changes of temperature to which it is submitted, occasionally loses its fibrous structure, and *becomes highly crystalline and brittle*. This change is especially seen in the axles of railway cars, and not unfrequently in the rails themselves. Hence the serious accidents which occur from the breakage of axles and rails, especially during the winter weather when the ground is frozen and unyielding.

The destructibility by fire of buildings constructed of iron is wonderful. Columns and beams which appear to have unlimited powers of resistance, yield in the most unexpected manner. This is largely due to the warping and the fracture which iron is apt to undergo, if water be thrown on it when it is heated to a certain temperature. The expansibility of the

metal also being much greater than the stone and brick with which it is combined, produces innumerable cracks and fissures in the walls, and so undermines their strength.

Of building materials not one equals well-made brick, in its power to resist the action of fire, and we may add of time. If the composition of bricks is of the right kind, they come out of the ordeal unharmed. Their edges even are unscathed. Water may be thrown on them when they are at any temperature, and they do not fissure. Stone of all kinds, on the contrary, is chipped, flaked, and cracked, both by the action of the fire, and also by the water thrown on it when heated.

75. Hypothetical Constitution of Solids.—The best summary of our present knowledge of this subject is that given by Prof. Crookes. It is as follows:

1. Solids are composed of discontinuous molecules separated from each other by a space which is relatively large—possibly enormous—in comparison with the molecule itself.

2. These molecules, composed of atoms, are governed by certain forces, viz., *cohesion or attraction, and motion.*

3. Attraction appears to be independent of absolute temperature; it increases as the distance between the molecules diminishes; and were there no other counteracting force, the result would be a mass of molecules in actual contact with no movement whatever—a state of things beyond our conception—a state, too, which would probably result in the creation of something which, according to our present views, would not be matter.

4. The force of cohesion is counterbalanced by the motion, which is also an inherent property of individual molecules themselves. These movements vary directly with the temperature, increasing and diminishing in amplitude, as the temperature rises and falls.

5. In solids the force of attraction or cohesion is greater than that of repulsion.

6. The molecules in solids do not travel from one place to another, but possess a fixity of position about their centre of oscillation.

7. Matter, as we know it, has so high an absolute temperature, that the movements of the molecules are large in comparison with their diameter, for the mass must be able to bear a reduction of temperature of nearly —300° C., before the amplitude of the molecular excursions would vanish.

8. The solid state is, in reality, merely the effect upon our senses of the motion of the molecules among themselves.

SECTION III.

LIQUID MATTER.

CHAPTER VI.

GENERAL AND SPECIAL PROPERTIES OF LIQUIDS.

Form not fixed—Resist compression—Compressibility—Elasticity—Porosity—Volume variations—Density or specific gravity—Table of specific gravities—Reunite behind a dividing solid—Hypothetical constitution—Liquidity and viscosity—Assume spheroidal state.

76. Form not Fixed.—Any liquid placed on a level surface spreads itself into a layer of greater or less tenuity, and, if the quantity is considerable, with no regularity of outline. The slightest tilt of the surface at once changes the outline and the thickness of the layer in different parts. Poured into a vessel of any shape, the liquid immediately adapts itself to the form of the vessel. Liquids, therefore, differ essentially from solids in that they do not have a fixed form.

77. Resist Compression.—In this respect liquids stand intermediate between solids and gases, the fixity of position in the molecules in solids giving them a great advantage over the other forms of matter.

78. Compressibility.—The experiments of the Florentine academicians, in which water oozed through the walls of a hollow globe of gold, led them to the conclusion that this liquid was incompressible, and for a long time that opinion was accepted. In 1761 the English physicist, Canton, found that when water was placed in an air-pump vacuum it expanded. The amount of expansion was 0.000044 of the volume employed.

In 1819 Perkins submitted water enclosed in suitable vessels to enormous pressures by lowering them to great depths in the ocean. The results of his experiments gave 0.000048 as the compression for each atmosphere of pressure.

A few years later Œrsted, by an instrument called the piézomètre, in which the pressure was obtained by a screw, found nearly the same results. The following table gives the values of compression per atmosphere obtained by M. Grassi, by means of the process of Regnault. The experiments were made at 0° C.

1. Mercury	0.000003	4. Alcohol	0.00008
2. Water	0.000030	5. Ether	0.000111
3. Chloroform	0.00006		

79. Elasticity.—A general definition of elasticity has been given in (45). In the case of solids this property exists in various forms, but in that of liquids, only in respect to volume. In solids the elasticity of compression is displayed within narrow limits, beyond which they are permanently compressible, as shown in the greater density given to many metals by hammering and rolling (see specific gravity, 59). In liquids, on the contrary, the amount of compressibility is greater, water shrinking $\frac{1}{100}$ of its volume under the pressure of a column of that fluid one mile in depth. On removing the pressure, a fluid returns rigorously to its original volume. The elasticity of liquids, therefore, is absolute under all ranges of pressure to which we can submit them.

In the case of solids, elasticity of compression was shown by the recoil of an ivory ball from the surface of a slab of stone (69). In the same way globules of mercury rebound from a hard surface. Molten antimony thrown on a table or floor gives an admirable illustration of the same property, bounding along, and leaving a dot of metal wherever it has touched.

The elasticity, contractility, and pliancy of the solid tissues of animals are largely owing to the presence of water. A dry muscle could not contract. Deprived of its water, the skin would lose all the physical properties which so eminently fit it for the purpose it serves. So important is water in the human economy, that no less than two-thirds of the whole weight of the body is made up of this ingredient. In an oyster 81 per cent. is water, and in certain jelly fish or acalephæ, 99 per cent.

80. Porosity.—Porosity in the case of solids has been discussed in (43). Though we cannot see pores, like the visible pores of a solid, in a liquid body, nevertheless some maintain their existence. In support of this doctrine the following experiments are given: The mixture of a pint of alcohol with a pint of water does not produce two pints, but much less. Gases, also, in enormous quantity, may be forced into water by the aid of pressure without any discoverable increase in the bulk of the

fluid. In both these examples it is as perfectly proper to suppose that the molecules of the alcohol or of the gas may occupy the intermolecular spaces. There is, however, one curious instance in which that explanation is hardly admissible, and the idea of the presence of pores seems the correct explanation.

If pure melted silver be exposed to air, as where a globule of that metal is kept in the fused state in a blowpipe-flame, it absorbs the oxygen of the air in considerable quantity (some 22 times its own bulk). On cooling, the gas escapes just before the metal becomes solid, and while it is yet pasty, as it were. In consequence of this escape of the gas, the metal is dragged out from the interior of the globule, and the exterior is covered by mossy or arborescent masses of frosted silver.

81. Volume Variations.—In solids these are exceedingly minute (51). In liquids they are much greater. The amount of expansion for a given rise of temperature is also greater at a high than at a low degree. As the liquid approaches its boiling point the rate of expansion becomes very irregular. Towards the freezing point a similar irregularity is noticed. For this reason liquids cannot be used in the construction of thermometers, except within ranges which are more or less distant from their boiling and freezing points.

82. Density or Specific Gravity.—Liquids, like solids, show considerable variations in specific gravity, from dense mercury and sulphuric acid to light, limpid ether. In a general way, it may be said that liquids are lighter than solids, and heavier than gases. As we have seen, there are many exceptions to the first of these propositions; if by solids minerals alone were meant, it would be much nearer the truth.

FIG. 9.

Specific gravity bottle.

The most satisfactory method for the determination of the specific gravity of liquids is by the specific gravity bottle, A. This is so constructed that it will hold a definite quantity of the liquid to be examined. The volume is accurately measured by the introduction of a stopper, B, provided with a capillary tube to give egress to any excess of fluid. The weight of the bottle and stopper is first determined while it is perfectly dry. The bottle is then filled with distilled water at 4° C. The stopper is introduced and all excess of water carefully removed by bibulous paper; it is then weighed. The weight of the bottle subtracted from this gives the weight of water it contained. The water is then removed, and the bottle rinsed with the liquid to be examined; it is then filled therewith at 0° C., and again weighed. The weight of the bottle

deducted from this gives the weight of the volume of liquid. The volumes of the water and the liquid being the same, it remains to divide the weight of the liquid by the weight of the water, when the quotient is the specific gravity of the fluid.

83.—*Specific gravities of liquids at 0° C. compared with that of water at 4° C. as unity.*

Mercury . . .	18.598	Distilled water at 4° C. .	1.000
Bromine . . .	2.960	Distilled water at 0° C. .	0.999
Sulphuric acid .	1.841	Claret	0.994
Chloroform . .	1.525	Castor oil . . .	0.969
Nitric acid . .	1.420	Cod-liver oil . .	0.928
Bisulphide of carbon	1.293	Olive oil . . .	0.915
Glycerine . .	1.260	Sperm oil . . .	0.875
Hydrochloric acid . .	1.240	Oil of turpentine . .	0.870
Blood . . .	1.060	Oil of lemon . .	0.852
Milk . . .	1.032	Rectified spirit . .	0.838
Urine . . .	1.030	Petroleum . . .	0.836
Sea-water . .	1.026	Absolute alcohol . .	0.793
Well-water, rarely as high as . .	1.005	Common ether . .	0.720
		Ether, absolute . .	0.713

84. **Reunite behind a Dividing Solid.**—This property is possessed in common by all liquids and gases. It may be said to be one of their distinguishing characteristics; solids, only in very rare instances and under extraordinary circumstances, exhibit it in a minor degree.

HYPOTHETICAL CONSTITUTION OF LIQUIDS.

85.—1st. Liquids are composed of molecules separated by interstices.

2d. The molecules are composed of atoms, as in solids.

3d. The force of cohesion is much less than in solids.

4th. The molecular movements are far greater in extent than in solids. They are also more tumultuous in their character.

5th. The forces of cohesion and repulsion are very nearly balanced.

6th. The molecules have no fixity of position, as in solids, but they travel from place to place.

7th. When heated to a sufficiently high temperature, the movements of the molecules become so excessive, and the consequent repulsions so great, that at last cohesion is destroyed, the molecules fly off into space with enormous velocities, and the gaseous state is assumed.

86. **Liquidity and Viscosity.**—We have said that the forces of attraction or cohesion, and of repulsion, nearly balance each

other in liquids. In different liquids, however, there are very different degrees of cohesion. In ether, naphtha, and alcohol, the cohesive force is weak; it is scarcely sufficient to enable us to blow bubbles, or if formed they are evanescent. On being agitated, such liquids are exceedingly mobile. Possessing the property of liquidity in the highest degree, the term *limpid* is used to indicate their character.

In other liquids the mobility of the particles is hampered, and their movements are sluggish, the effects of agitation are quickly lost. Examples of this group are offered by syrup, glycerine, sulphuric acid, and oils. To these the term *viscous* is applied; some of them, as soapsuds and glycerine, may be blown into bubbles of considerable size, which are quite permanent in their character. Albumen and mucus also impart this property in a high degree to fluids. The froth on an eggnog, made by beating white of egg, is a familiar example. In the case of urine, the mucus present imparts this property to such an extent that it becomes a serious impediment in the way of reading the specific gravity, the layer of bubbles on the surface of the fluid obscuring the scale and its figures.

The welding metals, as platinum, iron, potassium, sodium, in their passage from the solid to the liquid state also show this viscous character. Other solids, on the contrary, like ice, pass instantly from solidity almost to the extreme of liquidity of which they are capable.

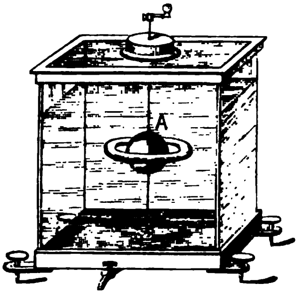
87. Assume Spheroidal State.—As vapor of water passes from the gaseous into the liquid condition, it first appears as minute spherical vesicles; these coalescing produce rain, which also closely approaches the spheroidal form. In like manner, water thrown in small quantities on the top of a red-hot stove, instantly gathers itself up into small spheres which drift about on the surface of the metal, supported on a cushion of steam which is formed on their under surface.

Other examples of this tendency of liquids to assume the spheroidal state are afforded by mercury when in a state of very minute subdivision. Melted lead also, as it passes through the sieve of a shot manufactory, assumes this figure in its descent through the air, and finally comes to us as solid shot, as nearly spheroidal as it is possible for anything to be.

The cause of the assumption of the spheroidal state by fluids is directly owing to, and is indisputable evidence of, the nearly equal balance between the two forces of cohesion and repulsion, associated with mobility of the molecules of the fluid. Another admirable illustration of this fact is offered by *Plateau's experiment*, in which a quantity of olive oil, A, is suspended in a

mixture of alcohol and water of the same specific gravity as the oil. Under these conditions the oil is freed from the influence of terrestrial gravitation, and, though several inches in diameter, the mass assumes an almost perfect spherical shape in the midst of the supporting alcoholic medium. When it is caused to rotate on its axis as is shown in the figure, a ring often forms like that around Saturn.

FIG. 10.



Plateau's experiment.

The approximately spherical form of the satellites, planets, and sun of our solar system, and also of the stars, is generally received as evidence that, in the course of their formation, they have at one time been in the liquid condition. In the case of our own earth, many facts tend to show that the interior is still either partially or wholly liquid, and the exterior solid crust only some fifty or one hundred miles thick. The tendency of fluids to assume the spheroidal state is, therefore, not only of interest in the study of small masses, but it has an importance and application that are only limited by the cosmos or universe itself.

Since the molecules of a liquid are exceedingly mobile, the complete study of their special properties makes it necessary that we should examine them, both in a condition of rest and of motion. The study of liquids at rest is called *Hydrostatics*, that of liquids in motion *Hydrodynamics*, and the application of these *Hydraulics*. The importance of the study of these subjects is dependent on the fact that they furnish the means for determining such physical properties of liquids as their specific gravity. They explain the causes of the circulation of the various fluids in the body. They treat of methods available for furnishing a copious supply of pure water and removal of liquid effete material or sewage. We shall, therefore, devote a chapter to each.

CHAPTER VII.

HYDROSTATICS.

Hydrostatics defined. Pascal's law—Hydrostatic bed—Hydrostatic test for steam boilers—Action of Pascal's law in the body—Vertical downward pressure—Vertical upward pressure—Lateral pressure—Equilibrium of floating bodies—Stability of floating bodies—Hydrostatic test in infanticide—Evidence of death by drowning—Equilibrium of a liquid in communicating vessels—Natural springs—Wells and sewage—Artesian wells—Equilibrium of two liquids ot different densities—Pressure on bottom of a vessel—Heterogenous liquids—Spirit level.

88. Hydrostatics Defined. Pascal's Law.—*Hydrostatics is the science which treats of the conditions of equilibrium in liquids, and of their pressures, either on their own mass, or on the walls of the vessels containing them.*

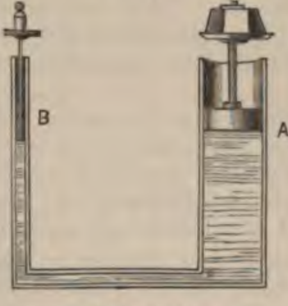
The law which underlies all the phenomena of hydrostatics is known as Pascal's law. It may be briefly stated as follows: *Since the molecules of a liquid are exceedingly mobile, a pressure applied on one portion of an enclosed mass of fluid must be equally resisted, and equally transmitted in all directions.*

Let a piston and cylinder, A, communicate with a hollow sphere, B, the walls of which are perforated by small tubes, C,

FIG. 11.

Equality of pressure in fluids.

FIG. 12.



Hydraulic press.

ending in jets. The sphere and cylinder being filled with water, and pressure applied to the piston, the water does not issue solely from the jets opposite the piston, but with about the same

freedom and force from all the jets, regardless of their position, thus demonstrating the equal distribution of the pressure in all directions.

This property of liquids gives us the explanation of the action of the *hydraulic press*, by which, from a moderate force, enormous pressures may be produced. It consists of a large cylinder, A, with a piston, the area of the cross section of which is 100 square inches. The lower part of A communicates with a small cylinder and piston, B, the area of which is 1 square inch. If on the top of the small piston a weight of one pound be placed, every square inch of the large piston will suffer the same pressure as that on the small piston. Being 100 times as large, the pressure will, therefore, be 100 times as great.

89. The Hydrostatic Bed.—The hydrostatic or water bed for the sick, in its first form, consisted of a water-tight box of the size of an ordinary sofa, and some 18 inches deep. In the box about six inches of water were placed. A sheet of water-proof material was laid loosely on the surface of the water, and fastened to the sides of the box. A thin mattress was then laid on the waterproof cloth, and on this a folded blanket. The water bed differs from the ordinary bed, in that the pressure on the body of the person lying on it is equally distributed over all portions of its surface of contact. Local pressures are impossible. The circulation in the capillaries is not interfered with, and consequently the formation of bed-sores is prevented.

In its recent form, the water-bed is a mattress, or large sack made of stout India-rubber, and filled with water. It is costly, and for this reason we have described the earlier form, which may be improvised, at a moderate expense, with the exercise of a little ingenuity. Water beds are of especial value in the treatment of fevers. They not only prevent the formation of bed-sores, but the relief from distress afforded during the early part of the attack, often prevents the disease from reaching a dangerous stage.

Since there is no necessity for changing the position to gain relief from pressure, as on ordinary beds, persons have sometimes remained unmoved for so long a time, on a water bed, that a serious stiffness of the joints has resulted; this should be prevented by occasional passive motion. Proper care should also be taken that the water with which the bed is charged is not too cold, as the patient might, in some instances, suffer thereby, either from shock or from too great an abstraction of caloric from the body. Especially should attention be paid to this matter in the case of a person suffering from phthisis. In certain febrile diseases the cold would be advantageous. If the dew point is high, and the water in the bed very cool, the bed-

ding would necessarily become damp by condensation of moisture of the air, and complications like rheumatism be introduced. Though an admirable contrivance, the water bed requires a great amount of attention in its use, not more, however, than any intelligent, humane physician ought to be willing to give in the interest of his patient.

90. Hydrostatic Test for Steam Boilers.—The law demands that from time to time all boilers for steam engines shall be submitted to a test by pressure, to determine their safety and ability to resist the elastic force of steam. For this purpose water is placed in the apparatus, a force pump is attached, and all outlets are closed. Pressure is then brought to bear upon all parts of the boiler by throwing the pump into action.

By this method weak points in the machine are detected. It yields quietly, and leakage occurs wherever there is a flaw in its construction. There is no explosion as would be the case with steam or air; there is therefore no risk to life in applying the test. The pressure thus applied is often double that for which the boiler is warranted by the inspector.

The difficulty with this test is that, by the great strain brought to bear, parts which would otherwise have resisted ordinary pressures for a long time are weakened, and consequently less able to bear strain afterwards. The test, moreover, does not entirely meet the requirements of the case; it applies a steady, continued strain. In actual use, on the contrary, the strain is a pulsating one. A throb is produced every time the steam passes from the boiler into the cylinder. It is evident that in the latter case the tendency to the loosening and wearing of the rivets and other parts of joints, must be much greater than in the former.

91. Action of Pascal's Law in the Body.—The examples are very numerous, especially in diseased conditions. Among these we may mention the pain and interference with the action of the heart attending effusion into the cavity of the pericardium; the torture suffered in the cavity of a joint when its unyielding walls are distended by accumulation of synovia; the effects upon the brain of accumulation of arachnoidal fluid within the bony walls of the cranium, or of effusion of blood therein.

The manner in which an aneurism, especially that called dissecting, finds its way between tissues depends upon this principle. The intolerable pain suffered when the bladder is overfilled with urine, arises from the same cause. So long as the urine accumulates in the bladder and it distends, the inconvenience may be borne. When the sac is full and the outlet closed, as in stricture of the urethra, the secretion of the fluid

continuing, the pressure upon the walls of the organ becomes so great as to be unbearable, and rupture occasionally results.

92. Vertical Downward Pressure.—Gravity produces internal pressures of different degrees in different parts of a liquid. The lower layers of the fluid contents of a vessel, evidently support a greater weight than those which are superficial. The pressures in different parts of a liquid depend on the following general laws:

1. *Pressure on any layer is proportional to its depth.*
2. *In unlike liquids the pressure at the same depth is proportional to their specific gravities.*
3. *In a given horizontal layer the pressure is the same in all its parts.*

Examples of the action of these laws are offered in certain diseased conditions of the human economy. In accumulations of fluid in the thoracic and abdominal cavities, certain positions are more endurable than others, according as they cause the fluid to press upon certain organs. The pleuritic patient naturally lies in the position which relieves his lung as much as possible from the pressure of the fluid accumulation. In dropsy, the fluid percolating between the spaces of the areolar tissue accumulates in the feet, and may cause but little discomfort. When it begins to rise into the legs the increasing pressure produces pain, and may even result in rupture of the skin. Change of position, by keeping the feet elevated, brings relief by reducing the height of the column of liquid which produces the pressure.

In the construction of the piers for bridges, where men are sometimes obliged to work in caissons under the pressure of a column of water sixty or seventy feet in depth, they pass through an intermediate valve or chamber to reach the open air. Thus the evil consequences of a sudden passage from extraordinary to ordinary pressures are to a large extent avoided.

In the estimation of the pressure at various depths, it is well to remember that the increase is very nearly *one pound to the square inch for every two feet of depth.* Hence it is that when a ship founders at sea, or a whale-boat is drawn to a great depth, the wood does not again rise to the surface. Every pore has become charged with the sea water, and its buoyancy is lost.

In houses in which water is distributed throughout the building, the usual boiler or receptacle for hot water in the vicinity of the kitchen range affords an example of the application of vertical pressure, and of Pascal's law. The pressure on the walls of such a boiler is far greater than would be supposed. It is continually under a very heavy strain, since from it, tubes pass often through many stories to a height of sixty feet, or even more. The pressure on every square inch of the boiler is, there-

fore, equal to nearly 30 pounds. If, while under this strain, the water be allowed to boil strongly, or a stopcock be suddenly closed, the thin metal of which the apparatus is made sometimes yields, and serious consequences result from the outflow of scalding water.

Where allowance is to be made for the actual weight of a mass of water, or of its volume, it may be estimated on the basis that *one cubic foot of water weighs nearly* $62\frac{1}{2}$ *pounds, and measures nearly* $6\frac{1}{4}$ *gallons.*

93. Vertical Upward Pressure is a natural sequent of the preceding. It is very evident, when we attempt to press the hand down in such a heavy fluid as mercury, or when we seek to pick up some object in water four or five feet in depth. The upward pressure of a liquid is called its *buoyancy;* it is proportional to the specific gravity of the fluid. An example of this is afforded in the greater buoyant power of sea water compared with fresh water, when we attempt to swim therein. The urinometer and all similar instruments depend upon the sum of the upward pressures of the layers of fluid through which they pass, for their action. The forcing of the lung into the upper part of the pleural cavity by effusion in the chest, is also dependent upon this upward pressure of fluids.

The laws governing the upward pressure of fluids are the same as those for downward pressure.

94. Lateral Pressure in Liquids.—In the construction of water tanks in the upper stories of dwellings, the question of pressure on the sides of the tank often becomes a matter of importance. The general law for such pressure, is that it "*is equal to the weight of a column of liquid, which has this portion of the side for its base, and whose height is the vertical distance from the centre of gravity of the portion to the surface of the liquid.*"

From the above law, it is evident that it is better to give such tanks considerable area of bottom, and small altitude. There is then but little pressure on the sides, and the great area of base distributes the weight better over the beams of the floor.

Where cemented walls of masonry are constructed to keep banks of soil in position, openings should always be left in the lower parts to allow for the escape of accumulations of water. If this is not done, the soil being wetted by a heavy rain, loses its consistency, and acting like a fluid mass will overthrow the wall, which cannot alone resist the pressure.

Landslides, which are so often attended by terrible results, especially when they occur along the banks of railway cuttings, are produced in a similar manner. The incumbent mass of earth rests on a stratum formed of clay of a peculiar consistency.

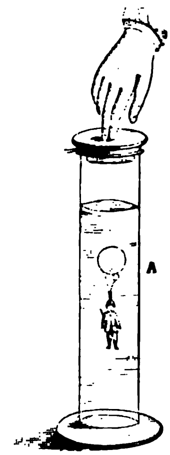
When the latter becomes soft by the percolation of water, it loses its sustaining power, and being for practical purposes reduced to the condition of a liquid, permits the whole mass of earth to slide down, as it would sink in water.

95. Equilibrium of Floating Bodies.—Two forces act on a floating body, viz., its gravity, which forces it downwards, and the buoyant power of the liquid, which presses it upwards. The conditions of equilibrium under these circumstances are:

1st. *The floating body must displace a volume of the liquid of equal weight.*

2d. *The centre of gravity of the floating body must be in the same vertical line with that of the displaced fluid.*

FIG. 13.



Cartesian diver.

The above principles, together with the effects of variation in the specific gravity of the floating object, are beautifully shown in the toy known as the Cartesian diver, Fig. 13, in which A is a cylindrical vessel filled with alcohol and water, in which a small glass figure containing air floats. The mouth of the vessel is closed by a sheet of India-rubber. When pressure is made on the rubber, the air in the upper part of the cylinder is compressed, the pressure is transmitted to the fluid, which is forced through an aperture into the interior of the figure. The specific gravity of the figure being increased, it sinks; release of pressure produces the opposite effect.

A device somewhat similar to the preceding is found in the swimming bladder of fishes. By allowing a part of the air contained therein to escape, they increase their specific gravity and sink. By increasing the included air, the body becomes lighter and rises. These movements are thus accomplished with scarcely any muscular effort.

96. Stability of Floating Bodies.—As the whole weight of a body is regarded as being lodged in its centre of gravity, so its whole flotation power may be regarded as being concentrated in its centre of buoyancy. The centre of buoyancy is the centre of gravity of the fluid displaced by the body.

That a floating body shall be stable and maintain its proper position in the fluid, its centre of gravity must be exactly below its centre of buoyancy. In the stowing of a ship's cargo this is carefully attended to, otherwise she will capsize. It has happened that when salt, sugar, or other substances soluble in water, have been placed in the hold, and water has gained access to the interior of the vessel, the salt or sugar dissolving

in the water has been pumped out in the bilge-water. The trim of the vessel being thus destroyed, shipwreck has followed.

97. Hydrostatic Test in Infanticide.—Advantage is taken of the principle of flotation, in what is called the hydrostatic test for the examination of supposed cases of infanticide and murder. The lungs of a fœtus never having been inflated with air, have little or no power of flotation. If, on the contrary, the child has been born and has breathed, the lungs having been once distended with air have considerable flotation power, of which they can only be partially deprived.

In a post-mortem, under such circumstances, the hydrostatic test should never be neglected. Errors may, however, arise. The hepatized lung of an infant would have but slight flotation power. Putrefaction of the lung of a fœtus fills it with gas, and gives it considerable flotation power. Both of these errors are, however, avoided by proper precautions. Regarding the supposed fallacies of the hydrostatic test, Woodman and Tidy in their "Toxicology" say:

1st, If we take care that the water is cool (not above 62° Fahrenheit); 2d, If we remember to cut the lungs into pieces, if the whole do not float; and, 3d, If we *combine pressure* with the floating, there is in reality no fallacy except the difficulty of distinguishing cases of artificial inflation from those of natural breathing. We suppose it must be conceded that it is not possible to distinguish, by any certain tests, the differences between lungs naturally expanded by breathing, and those artificially expanded by breathing into them. Though, as a generally true statement, it may be said that *lungs artificially inflated* are almost *sure* to be *emphysematous* in a far higher degree than is probable in lungs of the newly born which have not been so treated.

The conditions of the lungs in the two cases are given by the same authorities, as follows:

Lungs which have not breathed.	*Lungs which have breathed.*
1. Dark in color (black, blue, maroon, or purple). They resemble liver.	1. Light in color (rose-pink, paler pink, light red, or crimson).
2. Air-vesicles not visible to naked eye.	2. Air-vesicles distinctly visible to naked eye, or to lens of low power (say a two inch or common reading glass).
3. Do not crepitate or crackle when squeezed or cut.	3. They crepitate or crackle freely.
4. Contain but little blood, therefore little escapes on section.	4. Contain a good deal of blood, which escapes freely on section.
5. This blood is not frothy, unless there is putrefaction.	5. This blood is freely mixed with air, and therefore frothy.
6. They sink in water, unless putrid, and often even then.	6. They float in water, or, at all events, the parts which have been expanded or have breathed. If fully expanded, they will even buoy up the heart.
7. The bubbles of gas arising from putrefaction can be squeezed out.	7. The air cannot be easily squeezed out.

98. Evidence of Death by Drowning.—The manner of death of a corpse found in water is often a question of importance, and is not always easily settled. Persons who are drowning, in their struggles expel a large part of the air from their lungs and other organs. They also swallow a considerable amount of water; the specific gravity of the body is thereby so much increased that it usually sinks. Persons, on the contrary, who have been killed, and then thrown into the water, not having expelled the air from their bodies, may float near the surface.

If, therefore, a corpse in which there are no evidences of putrefaction, and in which death has only recently occurred is found floating, the presumption is that the person was murdered, and then cast into the water, though there may be no evidence of external violence. It is true that, after putrefaction sets in, the body of a drowned person comes to the surface. The cause, in this case, is the accumulation of gases from the putrefactive process. These have diminished the specific gravity of the body by increasing its bulk. In this case the sense of smell quickly shows the possible cause of flotation. We cannot tell from flotation alone whether death occurred before or after immersion in water.

Allowance must, of course, be made in this matter for the difference between the flotation power of the fresh water of interior regions and the brackish or salt water of sea-coast towns. The specific gravity of the latter being often as high as 1028, a corpse would float easily therein which would sink in the waters of an inland pond, lake, or river.

Death by drowning may be produced by a very small quantity of water. The following case occurred in New York. A gentleman was taking a face bath in a basin with about an inch of water in it; in some way he managed to drown himself, and was found with his face in the water. Whether it was a case of suicide or not, was a subject of question. Instances are not uncommon, in which persons have been accidentally thrown with their faces down in soft mud, and have expired in that position by drowning.

According to Woodman and Tidy: Fat people float the best. Women better than men. Fat young children and infants better than women. Bony, lean persons not at all. Sometimes bodies do not sink in sea-water.

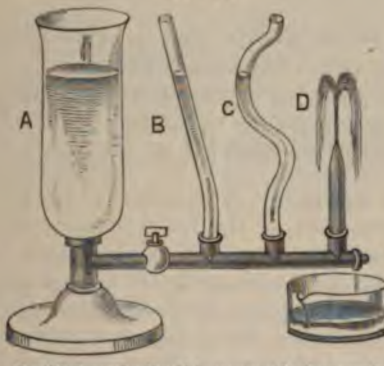
When weights are found attached to a corpse in the water, especial care should be taken to remark the manner in which they are attached, and the conditions of the parts, to determine whether it was possible for the person to have attached them before death.

In spite of the great flotation power of decomposing corpses, they frequently do not rise to the surface for a long time. In

such instances, they are either caught by some heavy object, or partly covered by mud or sand. In the latter case, it is said bodies have sometimes been detached from their moorings by firing cannon over the water. The shock of the discharge transmitted through the air to the water, jars the corpse, and so loosens it from its attachments.

99. Equilibrium of a Liquid in Communicating Vessels.—If tubes and vessels of different forms all open into one another below, as in Fig. 14, A, B, C, D, and water be poured into the vase A,

FIG. 14.



Equilibrium of a liquid in communicating vessels.

it will stand at the same horizontal level in all the tubes. Hence, in the supply of water to the houses of cities, all other things being equal, the water from the common reservoir will rise to the same level in all. At positions very distant from the reservoir, and with a heavy drain at numerous points upon the supply passing along the main pipes, this will not be true. If the amount drawn off is sufficient, there may be none at all at the distant points. The moment, however, the escape of the water is stopped, the law reasserts itself, and the fluid rises to the same level in all parts of the system.

100. Natural Springs.—These are formed when the level of the water in certain strata rises above the edge of the retaining basin in which it is held. As in the preceding system of tubes, the lowest one would determine the possible height of the fluid in the others, and the fluid would escape from it. So the lowest point in the edge of a natural basin permits the overflow of its liquid contents, and a spring is formed.

The same result is attained when wells are sunk into a stratum in which water is lodged or flowing. The water rises

in the cavity of the well to the same height it has in the stratum. We may, therefore, regard wells as being in reality springs, when they tap an underground flowing stream, and the water is as good as that of a living spring. When, on the contrary, they strike a stagnant basin of water, it, as a rule, is not as good as that obtained from the flowing stream.

If the strata in which water is lodged, or through which it has passed, contain mineral substances, as salt or chloride of sodium, Epsom salt or sulphate of magnesia, and other substances soluble in water, these are dissolved and constitute natural *mineral waters.*

If the mineral water contains only purgative salts, it is called *saline.*

If it contains these bodies, and is also freely charged with carbonic gas, it is called *effervescent saline.*

If it contains iron compounds, it is called *chalybeate.*

If it contains sulphuretted hydrogen, it is called *hepatic.*

If it contains iodides, bromides, or arsenic, it is called *alterative.*

101. **Wells and Sewage.**—Whenever wells are constructed in the vicinity of cesspools, if the level of the water in the well be lower than that in the cesspool, it will sooner or later be contaminated with the noxious products of sewage, on the principles laid down in the preceding articles. In the vicinity of cemeteries, also, the same thing has occurred, and persons who have used the water in either of these cases for the purpose of drinking, have suffered from typhoid fever and other diseases, the germs of which have been in this manner conveyed into their bodies.

Where wells are dug in gardens, or in close vicinity to stables or barnyards, the greatest care should be taken that no surface water from either of these sources reaches them, either in heavy storms or by percolating through the soil.

All water that falls on the earth must be more or less contaminated with the organic matter with which it comes in contact on its surface. As it passes to greater depths, and is spread throughout seams in rocks, and layers of sand and gravel, the oxygen it obtains from the air in these strata oxidizes or destroys these organic impurities. The water from springs and wells that are deep in their origin, though they may contain mineral ingredients, are free from such dangerous organic substances as are found in superficial waters. When water from deep springs is not available, it is much better to use rain water, which has accumulated in cisterns, lined with hydraulic cement, than to use surface waters.

102. **Artesian Wells** offer another illustration of the tendency of water to rise to its own level. In true artesian wells the

upon the mercury at the bottom will force the mercury up the opposite tube, B, and cause it to rise about one inch above its former level. We have already seen (83) that the specific gravity of mercury is more than thirteen and a half times that of water, it therefore follows that: *In communicating vessels, two liquids of different densities will be in equilibrium when their heights above the horizontal surface of contact are in the inverse ratio of their densities.*

104. Pressure on the Bottom of a Vessel is Independent of its Shape.—Let a conical vessel be in communication by its bottom with a narrow tube bent so as to rise vertically alongside of the conical vessel. Fill the bend of the tube with mercury. Pour water into the conical vessel, the pressure of the water upon the mercury will cause it to rise to a certain height in the narrow tube. Remove the conical vessel and substitute in its place a tube the sides of which are parallel, or even form an inverted cone when it is placed in position. Filling this with water so as to have a column of the same height as in the first case, the mercury rises to the same height in the narrow tube, showing that it is submitted to the same pressure.

In (91) we have spoken of the cause of pain in the bladder when the muscular coat is too much distended. We now see how the rise of the fluid in the ureters may suffice to produce this distention, since the pressure exerted in a liquid mass does not depend upon the quantity, but upon the height of the column of fluid producing the pressure.

105. Heterogeneous Liquids Arrange Themselves in Order of Density.—If petroleum, alcohol, saturated solution of caustic potash, and mercury be poured into a bottle, they will arrange themselves in the order given, the mercury being below. The lighter liquids, each according to its specific gravity, floats on the next denser one.

An application of this principle is shown in the method of determining the amount of *alcohol in wines* by the carbonate of potash. In a graduated tube, a measured quantity of the wine is placed, dry carbonate of potash is added, this dissolves in the water of the wine, and the alcohol being separated floats on the surface of the carbonate of potash solution. It only remains to read off the depth of the layer of alcohol, and compare it with the quantity of wine employed. We have a very fair approximation to the percentage of alcohol in the wine examined.

The determination of the amount of cream in milk is arrived at in the same way. A tube, known as the *cream tube*, graduated to 100 divisions, is filled with new milk. This is set aside for 24 hours. The cream, as it separates, being lighter

CHAPTER VIII.

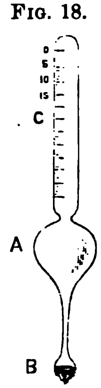
HYDROMETERS.

Baumé's hydrometer—Urinometer—Lactometers, vinometers, salimeters—Densimeter—Alcoholometer of Guy Lussac—Alcohol in wine and beer—Post-mortem detection of alcohol.

HYDROMETERS are instruments for the determination of the specific gravity of liquids. They depend for their action upon the principles discussed in the preceding articles. In the form of Nicholson's hydrometer, as we have seen (55), they may also be applied to the determination of the specific gravity of solids.

107. Baumé's Hydrometer was the first of a series of instruments of its type. The principle of flotation involved (95) is that in Nicholson's hydrometer. It consists of an elongated glass bulb or float, A, which terminates below in a small bulb, B, containing mercury or shot as a ballast to keep the instrument erect when placed in fluid, and sink it to a proper depth. From the upper part of the float a light tube, C, projects, in which a scale is placed.

FIG. 18.



Baumé's hydrometer.

This instrument, in its first form, is used by manufacturers for the examination of liquids heavier than water, as syrups, acids, and saline solutions. The graduation is conventional; it is made as follows: The apparatus being so constructed and ballasted that it sinks in pure water nearly to the top of the stem, this point is marked as the zero of the scale. It is then placed in a solution of fifteen parts of rock salt to eighty-five of pure water. The line the solution makes on the stem is then marked, and the value fifteen given to it. The distance between 0 and 15 is then divided into fifteen equal parts, and the scale so obtained is extended.

For liquids of less density than water, the plan is as follows: A solution of salt, ten parts, and water, ninety, being made, the instrument is placed therein and the level marked. To this the value 0° is given; it falls near the bottom of the stem. The instrument is then placed in distilled water, and the level on the

scale again marked, the value 10° being attached. This distance is then divided into ten parts, and the scale continued to the top of the stem.

These instruments do not determine the specific gravity, yet they are very extensively used. The readings are always given as so many degrees Baumé.

108. The Urinometer is a reproduction of the first form of the preceding, the difference being that in place of an arbitrary scale, it has readings which represent the specific gravity of the fluid under examination. The graduation is made as follows: The instrument is placed in pure water, it sinks nearly to the top. This is marked, and the value 0° or 1000 given to it. Solutions of salt and water of different specific gravities—*e. g.*, 1010, 1020 to 1060, are then prepared by means of the specific gravity bottle (82), and the instrument placed successively in these. The lines corresponding to the levels of the different solutions being marked, the intervening spaces are each divided into ten parts, and the scale so completed. To the figures 10, 20, attached to the scale, 1000 is to be added, when the gravity compared with water as 1000 is obtained. They are for convenience graduated at 15° C., and should be read at that temperature. Various forms of the instrument are represented at A, B, C, Fig. 19.

FIG. 19.

Forms of urinometers.

The following *rules for the examination and use of this instrument* are recommended to the student.

1st. Do not purchase an instrument without examining it with water to see if the 0° of the scale is correct. If this is in error, it is evident that as so little pains has been taken to have the initial point exact, no reliance is to be placed on the rest of the graduation. It is true that the zero may be right, and yet the rest of the scale incorrect. Any error of that description can only be determined by comparison with a standard instrument, the accuracy of which has been assured by the specific gravity bottle.

2d. In pouring the liquid into the cylinder hold it obliquely, at an angle of about 45°. The fluid will then flow gently down the side of the cylinder, without forming a foam. The presence of foam or of bubbles seriously interferes with the reading of the scale. It may be removed by a drop of ether, but it is better to avoid its formation.

3d. Stand with the back to the window or other source of light that the scale may be as brightly illuminated as possible, and also that the eyes may be protected from the light.

4th. The urinometer having been placed in the liquid, and there being sufficient fluid to float it freely, the cylinder is then to be held by the top, between the thumb and index finger. It should be held loosely, that it may hang perpendicularly like a plummet. By this device the tendency of the urinometer to become attached to the sides of the vessel will be lessened, and greater facility for correct reading attained.

5th. The level of the fluid in the cylinder must be brought to the same level as the eye. The horizontal line is easily obtained with sufficient accuracy, by selecting some object or point on the opposite side of the room, at the same height from the floor as is the height of the eye of the reader. The level of the fluid is then brought to this line.

6th. The fluid in the cylinder will be seen to rise as it approaches its sides. The liquid, therefore, has a curved instead of a plane surface. To avoid the error caused thereby, the reading should always be made where the lower convexity of the curve cuts the scale of the urinometer. It is also well to form the habit of counting backwards, that is, in reading a gravity of 1017, for example, read from 1020° upwards, rather than from 1015° downwards. The value of this device will be quickly seen in practical working.

7th. There is always a tendency to error from the urinometer hugging the sides of the cylinder. To avoid this at least three readings should be made, the urinometer being gently touched at its top between each reading to make it vibrate and break up any adhesions it may have formed to the wall of the cylinder.

From the readings of specific gravity of urine by urinometers, the attempt has been made to *calculate the quantity of solid matter therein*. Tables for this purpose are given in various works, but they are only approximate, since the quantity of solid matter depends on the nature of the ingredient of the urine which is in excess. It, of course, requires a much larger quantity of an ingredient of small specific gravity, than of one with a great gravity, to make a difference of a reading of one degree in the gravity of the whole mass of liquid. The only correct method for the determination of the actual quantity of solid residue is to evaporate a known weight or volume of the urine, or other liquid to dryness, and to weigh the resulting residue, with proper precautions for preventing the absorption of moisture during the cooling and weighing of the mass.

109. Lactometers, Vinometers, Salimeters, are instruments on the same principle as Baumé's hydrometer. They do not give

the specific gravity, but are intended to show whether or no water has been added to the fluid for which they are adjusted. They have little or no scientific value, especially in the case of the so-called lactometer, which is intended to detect the addition of water to milk. An example will perhaps best illustrate the point in question. Suppose a rich specimen of milk be given, it records its richness on the lactometer scale. The cream now rises, and being removed or skimmed off, the gravity of the milk will be increased. By the addition of water the original gravity may be restored, but the lactometer fails to detect as an adulteration the water which has been added.

Another very simple sophistication is to add to the milk, water in which some kind of innocuous salt has been dissolved, until it has the same gravity as that of unadulterated milk. Again, the lactometer is deceived. There is only one reliable way to ascertain the addition of water to such complex organic fluids as milk and wine, and that is by a quantitative analysis, in which the actual proportions of the water and of other leading ingredients are determined by weight.

110. The Densimeter is a form of hydrometer intended for the determination of the specific gravity of small quantities of liquid.

Rousseau's densimeter, Fig. 20, consists of an ordinary hydrometer, B, to the upper part of the stem of which, C, a little cylindrical vessel, A, is attached. This should have a capacity of one cubic centimetre. When this vessel is empty, and the instrument is placed in distilled water, the level of the water crosses the 0° of the scale, which is at the bottom of the stem B. One cubic centimetre of water is now introduced by a pipette into the cup at the top of the stem, when the instrument sinks in the water, and the level on the stem is marked and the value 20° attached. The space between 0° and 20° is then divided into twenty parts, and the graduation continued to the top of the scale. The stem being of uniform bore, each division represents one-twentieth of a gramme or 0.05.

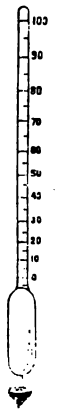
FIG. 20.

The densimeter.

To obtain the specific gravity of a liquid, place the apparatus in distilled water. From a cubic centimetre pipette drop 1 cubic centimetre of the liquid into the cup. Suppose the water cuts the scale at twenty and one-half divisions. Then $20.5 \times .05 = 1.025$, the specific gravity of the liquid, water being 1.

111. The Alcoholometer of Guy Lussac is a hydrometer graduated to show the percentage of alcohol in spirits, or in mixtures of alcohol and water. It is similar in form to Baumé's hydrometer, but differs therefrom in that the water-line or 0° is at the bottom instead of the top of the stem. The instrument is graduated by placing it in successive mixtures of alcohol and water of strengths differing in proportion by 10 per cent. of alcohol, and finally in absolute alcohol. The last is then marked 100 per cent. The lines obtained from the other mixtures 90, 80 to 0°, receive their respective values. The spaces between each of these is divided into 10 divisions, each of these subdivisions marks one per cent. of alcohol in the mixture. To the stem of the instrument another graduation representing specific gravities is very commonly attached.

FIG. 21.



Alcoholometer.

112. Determination of Alcohol in Wine and Beer.—The determination of the percentage of alcohol in wines, ales, and similar liquids, in which other substances are present, is as follows. A known quantity of the fluid must be carefully distilled, until the whole of the alcohol has passed over. To the distillate sufficient distilled water is added to make its volume equal to the original volume of the wine or other fluid under examination. The percentage of alcohol is then determined by the alcoholometer, when the result represents the percentage in the original liquid.

113. Post-mortem Determination of Alcohol.—In cases of the death of children or of adults by alcohol poisoning, the method to be followed is similar to that detailed above. The contents of the organs, the finely chopped brain, or other tissue, with or without mixture with water, are to be distilled over the water-bath. If alcohol is present, the percentage and quantity in the distillate may be determined by the alcoholometer.

CHAPTER IX.

HYDRODYNAMICS.

Definition—Theorem of Torricelli—Course of stream from lateral opening—Height of stream from vertical opening—Form and quantity of efflux—Influence of tubes on efflux—Action of elastic ajutages—Movement of liquids in tubes—Form of falling stream—Movement in inclined tubes—Hydraulic tourniquet—Velocity in open channels—Transporting power of flowing water—Shoals and sewage—Sewage and malaria—Formation of waves—Sea waves—Measurement of waves—Resistance of fluids to moving objects—Mechanics of circulation of the blood.

114. Hydrodynamics Defined.—*Hydrodynamics is that branch of physics which treats of the laws governing the motion of fluids. It examines into the manner and rate of escape of fluids from outlets. It determines the conditions and rate of movements in tubes and in open channels.*

115. Theorem of Torricelli.—The velocity of a molecule of a liquid escaping by an aperture in the walls of a vessel is the same as it would have if it fell freely from a state of rest at the surface of the liquid to the centre of the orifice.

FIG. 22.

Torricelli's theorem.

The rate of efflux depends, therefore, on the depth of the opening, A B, beneath the surface of the liquid, M N. It is immaterial whether the orifice be in the bottom or in the side of the vessel. Difference in specific gravity does not influence the rate. Water has the same velocity as mercury, provided the diameter of orifice and depth of fluid are the same.

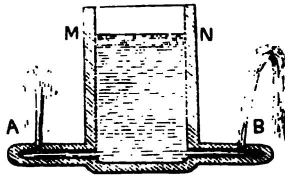
116. Course of Stream from Lateral Opening.—The axis of the opening being horizontal, the course of the stream is, at the first moment, also horizontal, but the attraction of gravity acting upon it immediately, the particles of fluid fall from the horizontal, and assume a curved line.

The curves thus formed are parabolic, and, according as the

pressure at the orifice is greater, so do the parabolas formed by the issuing streams vary.

117. Height of Stream from Vertical Opening.—From the principles laid down in vertical upward pressure (93), a stream issuing from an orifice opening vertically upwards, as at A in Fig. 23, should rise to the level, M N, of the fluid in the reservoir. This it does not do: 1st. It is beaten down by the falling drops. 2d. It is drawn down by gravity. 3d. It is resisted by the air. If the stream is slightly inclined to the vertical, as at B, a better result is obtained, but at the best it only reaches about $\frac{9}{10}$ of the theoretical height, friction of the air and gravity reducing it to this extent. Allowing for these reductions, the result sustains the theorem of Torricelli.

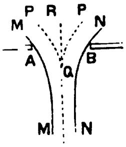
FIG. 23.



Stream from vertical opening.

118. Form and Quantity of Efflux.—According to theory, the amount of water discharged from a circular opening in the thin walls of a vessel should be expressed by the formula $A\sqrt{2gh}$, in which A is the area of the opening, g the accelerating force of gravity, and h the height of the liquid. Actual experiment gives a very different result. Of this, Ganot offers the following discussion: Let A B represent an opening in the wall of a vessel. Every particle above will attempt to pass out, and so exert pressure on those around it. Those issuing near A B press in the lines M M and N N; those at the centre in the line R Q, and the intermediate ones in the lines PQ PQ; consequently the water in the space PQ P cannot escape. That which does pass out takes the form of a truncated cone, or *vena contracta*, and not of a cylinder, until it has reached a distance from the orifice equal to the diameter of the same. The area of a transverse section of the stream at this point is 0.62, or about $\frac{5}{8}$ that of the orifice. The actual quantity passing out is, therefore, but five-eighths of what might have been expected from the diameter of the opening.

FIG. 24.

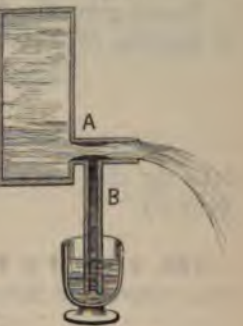


Vena contracta.

119. Influence of Tubes on the Efflux.—If a cylindrical tube, having a length two or three times its diameter, be made the channel of exit of the fluid, the efflux increases to 0.82 of the theoretical quantity. A tube of proper proportions, and n the form of a truncated cone with its base at the opening, may

be made to raise the efflux to 0.92. If the smaller end of the cone be adapted to the aperture, the increase is still greater, and very little below the theoretical quantity. To these tubes the name *ajutage* is given. When a cylindrical ajutage of the proportions stated above is used, the water on entering it forms a *vena contracta*, A, in the same manner as in the air; it then expands. A partial *vacuum* is thus formed in the position indicated in Fig. 25. If a vertical tube, B, is attached to the ajutage at this point, and its lower extremity dips into a fluid, the latter will rise in the tube, thus demonstrating the existence of the vacuum.

Fig. 25.



Efflux in tubes.

Upon the above principles, or slight modifications thereof, various modern appliances, as Bunsen's filter-pump, Giffard's injector, and certain forms of atomizing apparatus, commonly used in medicine, depend for their operation (177).

120. Action of Elastic Ajutages.—If an elastic tube of rubber be adapted to an outlet in a vessel, the rate of efflux is the same as by a rigid tube having a diameter equal to that which the elastic tube assumes. If, on the contrary, the flow is by any device made intermittent the results are entirely different. The elastic tube now shows a notable increase in efflux over the rigid one. The manner of discharge is also very different. While the jet from the rigid tube reproduces every impulse of the original intermittent action, that from the elastic one shows great diminution therein, and if the ajutage tube be of sufficient length the pulsation completely disappears.

These observations are of importance in the explanation of the manner of flow of the blood in the arteries, the coats of which are highly elastic.

121. Movement of Liquids in Tubes.—Though the mobility of the molecules of liquids is great, it is not absolute. Hence arises a certain degree of friction among the molecules themselves, and also between the fluid molecules and the walls of the tube. In the latter case it is much greater than in the former, as may be seen in the more rapid flow of the water down the central and deep portions of a river, compared with its rate near the banks or over shoals.

Hydraulic friction, which is the term applied to the resistance which we have been examining, is independent of the material

of which the tube is made. It is increased by roughening its walls. It depends chiefly on the character of the fluid, whether it be viscous or limpid. In this respect ice-cold water shows a slight degree of viscosity compared with that which is lukewarm.

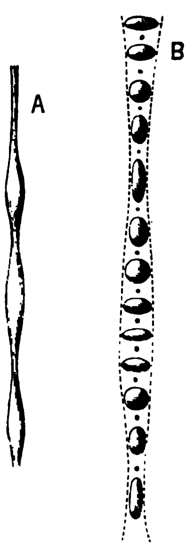
Prony gives the following as the formula for the mean velocity, in metres, of water in a cast-iron pipe:

$$v = 26.8 \sqrt{\frac{dp}{l}}$$

l being the length, d the diameter, p the pressure, and v the velocity.

122. Form of a Falling Stream.—From the lower end of the *vena contracta* a falling stream of water takes the form of a continuous cylinder for a short distance. The accelerating action of gravity soon causes it to break into drops. The stream now assumes the appearance shown at A, of alternate nodal and ventral segments. In the nodal segments, the drops are extended longitudinally; in the ventral, transversely to the course of the stream.

FIG. 26



Forms of falling water.

As these segments have a fixed position, it follows that each drop in its descent passes through the phases shown at B.

Under illumination by the condensed electric spark of an induction coil, the drops appear to be stationary, and their forms can be studied to advantage.

123. Movement in Inclined Tubes.—If in place of falling freely in the air, as is the case in the preceding article, the stream is falling in a vertical tube, the action of gravity will tend to produce the same effect. The lower parts having a greater velocity than those above, and the stream assuming the nodal and ventral form, will, in its latter state, act as a piston in the interior of the tube. Thus a vacuum will tend to form above each ventral part. To meet this the pressure of the air will be called into play on the surface of the reservoir from which the pipe issues, and a great acceleration of the efflux will ensue. The energy of the action thus evoked is shown in the suction or noisy draught with which the last portions of water are

drawn out from a wash-basin or bath-tub, the exit pipe of which is long and perfectly free.

The presentation we have given above of the case in a vertical tube, applies less and less as the tube leaves this position and inclines towards the horizontal.

The principles which we have been discussing are of importance in the construction of the waste-pipes or drains of houses. Their application will be found later on. See (149).

124. Hydraulic Tourniquet.—Fig. 27 represents the instrument in question. It consists of a pear-shaped vase, V, filled with water, and so mounted as to revolve freely on its vertical axis.

FIG. 27.

Hydraulic tourniquet.

From the smaller and lower end of the vessel, two tubes project horizontally, which are continuations of a diameter. The outer extremity of each of these is bent horizontally, at a right angle to the shaft, as is shown at A in the figure.

The opening of the extremity of each tube being closed, the liquid in the vase exerts an equal pressure on all parts of the wall of the tube, and the instrument is at rest. When the end of a tube is opened, the pressure on that side is relieved. The tube is then forced backward by the pressure on its opposite sides in the direction of the dotted line, and a rotatory motion is produced.

Under the pressure of a head of water the vase may be dismissed, and the apparatus attached directly to the tube supplying the water. In this manner a very convenient form of power is obtained, the discussion of which belongs properly to hydraulics as applied in the turbine.

125. Velocity in Open Channels.—We have already had occasion to refer to the effects of hydraulic friction, as shown in the greater rapidity of movement in the deep parts of a stream as compared with that in its shallows. Were it not for the resistance afforded by friction, a river which originates in a source 1000 feet above the level of its mouth would have the velocity of water issuing from the bottom of a lake 1000 feet deep, or a rate of nearly 170 miles an hour.

By the double action of the friction of the molecules of water on each other and on the banks of the stream, the rate is ordinarily from three to five miles per hour, and the inclination of the channels from three to five inches in the mile.

126. Transporting Power of Flowing Water.—The transporting power of running water involves two conditions: 1st. *The force, or actual pressure of the moving mass;* 2d. *Its buoyant power.* Owing to the combination of these two causes, it is estimated that if the rate of flow of water be doubled, its power of transportation is increased sixty-four times.

Evidence of the fearful power of water in rapid motion, is shown by the manner in which mountain streams wrench masses of rocks from their foundations and hurl them down their course, until, by striking against each other, they are so pulverized that only an impalpable powder remains, which, when it settles, is called *silt.*

It is estimated that the Mississippi River carries to the Gulf of Mexico, annually, an amount of solid matter equal to a mass one square mile in area and about 270 feet deep. It is easy to see that under these circumstances the deposition of the matter transported by rivers becomes a question of importance, as regards the disposal of the sewage of the cities on their banks and at their mouths.

127. Shoals and Sewage.—When the sewer system of New York was first constructed, and for some years thereafter, the effete materials were immediately swept into deep water, and carried by strong currents to a distance from the city. Since that time, by the extension of piers, deposit of cinders, washings of filth from the city streets, and largely by the silt brought down by the Hudson in spring freshets, shoals or bars have been formed. These have seriously modified the direction and

force of the currents in the waters of the river front. As a consequence, the sewer filth no longer passes into the current of deep water, but is deposited in the slips between the docks. The seething mass of putrefaction that forms the water-bed in such localities, is at all times throwing off various effluvia, among which is sulphuretted hydrogen, which may be detected throughout the year by its odor. In the summer time, when the action is more energetic, it may be seen rising in millions of bubbles to the surface, and the odor then becomes almost intolerable in certain localities.

128. Sewage and Malaria.—Of all the ordinary gases none is more dangerous or insidious in its action than sulphuretted hydrogen. It is one of the so-called cumulative poisons. It acts upon the blood discs, impairing, and even destroying their function as carriers of oxygen. It thus reduces the power of the system to resist disease, and lays it open to attacks which would otherwise have no effect. It even seems to be in some way related to the development or presence of malarial poison, for, in localities where deadly forms of malarial diseases prevail, sulphuretted hydrogen is almost always to be found in the air.

The proper methods for the correction of these troubles in great seaports may be arranged under three heads, viz.: 1st. The removal of all garbage, horse-droppings, and other filth from the streets, and its sale as a fertilizer. Thus the largest part of the noxious organic matter would be prevented from gaining access to the sewers, slips, and harbor basin.

2d. The extension of the sewers to the pier-heads, where they may discharge into deep water. The sewer itself should end in an arm turned down at right angles, like the termination of the ordinary stopcocks used in houses. To this point the level of the sewer should not be below high water. The final opening of the termination should be below lowest water mark.

3d. All accumulations, banks, or bars, which interfere with the original water-course and free passage of sewage into the main current, should be removed. This is a subject of hygienic importance which should not be overlooked. It is scarcely a matter of wonderment that under the present management of such affairs in the city of New York, it has become a malarial city. It cannot fail to be so until better disposition is made of the sewage and filth that are now permitted to accumulate on its river fronts.

It needs no apology, in view of such grave matters as these, to urge upon physicians a better knowledge of physics, even to the proper understanding of the manner of flow and formation of currents in the harbors of the cities they inhabit. No one in a community has the same interest in the subject as its phy-

sician. No one has better opportunities of seeing the consequences of neglect of proper precautions. If it is not his business to attend to such matters and show how they are to be met and remedied, to whom, in the name of common sense, does it belong? His duty to the community demands at least, that he shall initiate the discussion of these questions. To do this he must have a sufficient knowledge of the subject to agitate it intelligently.

129. Formation of Waves.—When a pebble is dropped into a pond of smooth water, it displaces a portion of the fluid laterally, and a circular elevation or wall of liquid is raised around the spot of impact. This elevation, following the laws of fluidity, gradually widens. The depressed portion where the pebble struck, pressed upon by the surrounding elevation, which causes upward pressure from below, returns to and rises above its original level. It thus, in its turn, becomes a source of disturbance, and acting like the impact of the pebble, produces a second circle of depression and elevation. This oscillation continuing, alternate circles of elevations and depressions, or waves, are produced, each becoming wider and wider, until at last they reach the margin of the pond, where they may be either broken or reflected.

To the eye it appears as though, in the expanding circles of waves, the water was itself following the course of the wave, but it is not so. If a chip of wood, or any other light body, floating on the water is observed, it will be seen that it has little or no outward motion. As the wave approaches, it gently rises; as the wave passes, it falls.

Since the chip merely copies the movements of the molecules of the water on which it is resting, we thus learn that the latter have little or no movement in the horizontal plane, or in the longitudinal direction of the wave motion. They move, on the contrary, in a vertical plane, or transversely to the course of the water wave. As in the case of the undulations we may pass along a rope, which is fastened at one end, while it is moved up and down at the other; it is the form that advances in the track of the wave, not the substance. That is moving at right angles to the wave motion.

By virtue of the friction between the molecules of water, the new waves reach a less and less altitude than their predecessors, until finally the disturbance ceases, and the surface of the water becomes as unruffled, and mirror-like, as when the stone first struck it.

130. Sea Waves.—As flowing water develops friction against the banks of the channels in which it is passing, so currents in

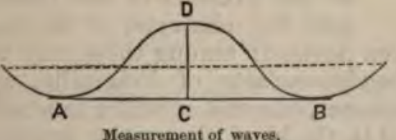
the air produce friction upon the surface of the water over which they move. The little gusts of wind that strike upon smooth water cause the instant appearance of ripples on its surface. If the velocity of the wind is great, and its application persistent, the ripples in time become waves, and these increase in volume and breadth until finally the rolling mountains of the ocean are formed.

The rate of motion of these ocean waves is dependent upon their volume. In waves of great magnitude, like those off the Cape of Good Hope, the velocity may be as great as thirty or forty miles an hour.

The mobile surface of water permits the propagation of waves over immense distances. This, combined with their velocity, will often carry intelligence of storms to distant shores, by the heavy breakers that fall upon them when no wind is blowing.

131. Measurement of Waves.—Waves on water may be measured in two ways: 1st, wave length; and, 2d, wave height. In the diagram, the distance, A B, from the centre of one depression to the centre of the next, is the wave length. The same

FIG. 28.



Measurement of waves.

measure may also be applied from the centre of one crest to the centre of the next, or from the middle of one wave to the middle of the next.

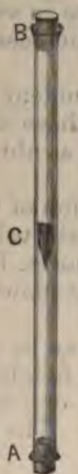
The wave height is measured by the line C D, drawn from the horizontal line connecting two depressions, and perpendicularly to it, to the top of a crest. Sometimes the total elevation is divided into wave and trough, the former being above the ordinary sea level, the other below it, as shown by the dotted line. In that case, the wave height is one-half of C D, and the wave depression the other half.

In great waves at sea, the elevation of the water above the ordinary level is rarely more than fifteen feet, making the total height, from bottom of trough to top of crest, thirty feet.

132. Resistance of Fluids to Moving Objects.—Water, by its partial viscosity, experiences resistance on the surfaces over which it is moving; so, on attempting to move a body through water, resistance is in like manner developed.

An experimental illustration is afforded of this fact, as represented in the figure. Let A B be a tube 2 feet in length, and closed by corks at each end; a Minie-bullet, C, is to be introduced. On quickly inverting the tube, the bullet falls immediately from one end to the other, in a small fraction of a second. On filling the tube with water instead of air, and repeating the experiment, it will be found that it now requires many seconds for the bullet to fall from end to end.

Fig. 29.



Resistance of fluids to moving objects.

Another fact is at the same time perceived. When the bullet is descending with its point downwards, its velocity is much greater than when the butt or blunt extremity is foremost. The resistance offered by liquids to the passage of a moving object is, therefore, largely dependent on the form of the object, those which are pointed or wedge-shaped moving with the greater velocity.

132 A. Mechanics of the Circulation of the Blood.—Various devices for the measurement of the pressure of the blood in the arteries, and the character of its movement in these vessels have been devised; among these may be mentioned:

1st. The *hæmadynamometer* of Poiseuille, which is simply a U-shaped manometer, one end of which is attached to the artery, while the liquid in the bend shows the pressure exerted by the blood.

2d. The *kymographion* of Fick, by which the inertia of the mercury in the preceding apparatus is avoided. It is a complex apparatus consisting of a hollow spring filled with alcohol, and terminating at one end in a system of levers which record by a point on a revolving cylinder; the other end is brought in communication with the bloodvessel to be examined.

3d. The *cardiograph* of Marey, consisting of a tambour adapted to the exterior of the chest over the region of the heart; its indications are recorded by another tambour.

The same method has been adapted to the examination of the action of the heart itself, by introducing into that organ a kind of catheter bearing a bag or tambour at its extremity, and communicating with a registering tambour externally.

4th. The *hæmadromometer* of Volkmann, for the measurement of the speed of the flow of the blood. The *stromuhr* of Ludwig, is an improvement upon this, and admits of more accurate results. The *hæmatachometer* of Vierordt, and the *dromograph* of

Lortet, are other applications of the same principle for the same purpose, viz., measurement of current velocity.

5th. The *sphygmograph* for recording arterial tension was originally devised by Vierordt, and improved by Marey.

6th. The *gas-sphygmoscope* by which the impulses of the artery are communicated to a small chamber, through which gas is passed and then ignited. The variations in the form of the flame show the variations in the condition of the artery.

7th. The *sphygmophone*, a modification of the preceding, in which the flame is burned inside of a tube so as to produce a singing flame. To this the pulsations of the artery impart a kind of beat readily perceived at a distance.

For a more thorough explanation of these forms of apparatus the student is referred to modern works on physiology.

CHAPTER X.

HYDRAULICS.

Definition—Earliest devices for raising water—Pulley wells—Archimedes's screw—The Persian wheel—The siphon—The flexible siphon—The intermittent siphon—Pumps and valves—Lift pump—Force pump—Hydraulic ram—Water wheels—The turbine—Centrifugal pump—Materials for hydraulic engineering—Sewage in houses—Utilization of sewage—Marsh draining and malaria.

133. Hydraulics Defined.—*Hydraulics is the application of the principles of hydrostatics, hydrodynamics, and also of pneumatics, to the construction of apparatus for the collection, storage, and distribution of water or other fluids. It also includes the utilization of water as a source of power.*

The difficulty of separating hydrodynamics from hydraulics has been seen in the discussion of the hydraulic tourniquet, and in other instances. In like manner, the description of pumps certainly belongs to hydraulics, though their action is to be explained on the pneumatic principles involved in the pressure of the air. In all cases where this difficulty of arranging subjects in their proper positions has arisen, we have followed the course which seemed to present the most practical advantages and the greatest simplicity.

For convenience the study of hydraulics may be divided as

follows: 1st, Apparatus without valves for raising water; 2d, Valvular apparatus for raising fluid; 3d, Development of power; 4th, The conveyance of fluids.

Apparatus without Valves for Raising Water.

134. **Earliest Devices for Raising Water.**—Doubtless the first cup of our ancestors was the palm of the hand hollowed by the contraction of the muscles. Following on this, and in the order of development as it were, we can easily imagine that a leaf bent and hollowed like the palm of the hand came into use. Then any naturally hollow vegetable product, as the shell of the cocoanut, and coverings of various fruits, also sundry animal products, as the emptied eggs of large kinds of birds, and shells of mollusks. Next came the fashioning of vessels of clay, first dried in the rays of the sun, and afterwards baked by the heat of a fire.

For the raising of water from natural springs these devices sufficed. When the spring was surrounded by a low wall to protect it from being soiled by cattle, some little improvement was needed. Here we can see the origin of the dipper, made perhaps as we now so often find it, out of the half shell of a cocoanut, to which a forked stick is attached as a handle. In copying this in earthenware, what more natural, on account of the fragility of the material, than to substitute the curved handle we now find attached to our tea-pots and cups.

From the earthenware vessel with its handle on the side, which could not be conveniently used for purposes of carrying quantities of water to a distance, the passage to an earthenware vessel, with a straight rod run through two holes near its upper part, was easy and natural. Now the mass of water could be balanced and carried in the vessel, though it was filled nearly to the top. The next improvement, whereby the balancing of the filled vessel was made more facile, was to substitute a curved stick, or piece of vine, for the straight rod, and a pail which might also be used as a pot for boiling over the fire was formed.

In dry seasons, as the water in springs fell, the simple and obvious remedy was to follow it down by removing the earth from the bottom and so digging it out. In doing this, to prevent the soil from falling in, the wall which surrounded the spring was carried down, and so the first wells came into existence. The earthenware vessel described above, or one of wood hollowed out, perhaps by the action of fire, with its curved handle, and a long piece of some vine, gave easy access to the water. So the original of the "Old Oaken Bucket" came into existence.

For the purposes of irrigation, where water was raised from rivers or wells for many hours in succession, it was necessary to relieve, as far as possible, the strain on the muscles produced by always throwing the chief work on one process, *i. e.*, that of pulling the bucket up. This was accomplished by the invention of the lever arrangement depicted in the figure, and which, though it first came into use thousands of years ago, is still employed in nearly all parts of the world. It is doubtful if any

FIG. 30.

Raising water in wells, early method.

human contrivance has held its ground for so long a time, or been so universally applied, as the one in question.

135. Pulley Wells are another device by which, in place of pulling upwards, force is applied to pull downwards, and so advantage is taken of the weight of the body. It consists of a rope which passes over a grooved wheel, or pulley, in the top of the well house. To each end of the rope a bucket is attached. The buckets balancing each other, their weight is eliminated, an additional advantage to that of applying the force downwards instead of upwards.

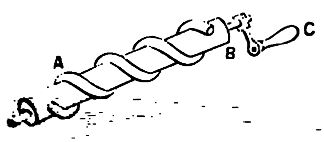
An early improvement in the use of the pulley was to substitute the *axle and winch* therefor. At first it was applied to a single bucket to reduce the effort required to raise it when filled with water. Afterwards it was modified, a series of buckets being attached to an endless rope. These passing under a wheel in the water of the well were filled, and emptied as they surmounted the wheel above, which gave motion to the apparatus. This device is still in operation in harbors for the purpose of dredging, or raising accumulations of soft mud.

In place of a series of buckets, an endless chain is sometimes arranged with disks about a foot apart. This is passed through a tube. The disks fitting the tube as closely as possible, carry the water upwards when the chain is passed through the tube rapidly. This constitutes the *chain pump*, and is very useful

. . . be raised, since it is not so apt to . . . ordinary pump, or if it does, relieves . . . action. For the chain and disks a rope . . . stituted.

. . . screw is another ancient device well adapted . . . s of water to a moderate height. It con- . . . at both ends, and wound spirally around . . . n the figure. As the cylinder is made to . . . the lower end of the pipe dips under . . . sed along the tube as up an inclined plane. . . . shaft, or cylinder, to the horizon should . . . The pipe should make about three or . . . at an angle of about 60° to its axis.

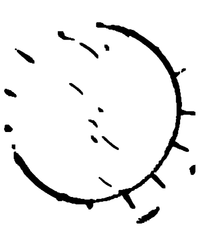
FIG. 31.



Archimedes's screw.

. . . e most economical device for raising water, . . . waste of power. It is extensively used in . . . cases of draining, the motive power being a . . . so used in France, the motive power being . . . e sometimes five or six feet in diameter. It is . . . to raising sewage, and might in that case be . . .

37. **The Persian Wheel** is a large wheel with paddles, A A, which dip into a stream, the water of which has sufficient rapidity to cause it to turn. The margin of the wheel also carries buckets, which fill below and discharge into a trough at the top of the wheel. The water of the stream is thus forced to raise itself. A modification of this arrangement is depicted in the figure. In this the spokes, B B, of the wheel are troughs or tubes curved in the



. . . shown. When their extremities dip into the water, a . . . the fluid is taken up and carried to the axis, X, of . . . where it is discharged along a tube.

138. The Siphon.—Where an elevation intervenes between the source of water and the place where it is used, it may be passed over the hill by a siphon. The vertical height to which the fluid may be raised cannot be more than thirty-four feet above the level of the water source.

The siphon consists of a bent tube, open at both ends, as is shown in the figure. The arm B is longer than the arm A. The extremity A being placed in water, and the entire length of the tube filled therewith, the longer column of water in B tends to fall out of it; an exhausting action is thus produced in the curved portion of the tube. The air pressing on the surface of the water at A, forces it up into the tube, and as fast as it reaches the curve it turns into B, and passing down a continuous flow is established.

The greater the length of the long arm, compared with that of the short arm, the more rapid is the flow through the siphon.

Fig. 33.

The siphon.

The siphon offers an example of the association of hydraulics with pneumatics, for the force brought into play is the pressure of the air, as we have stated. This is easily shown by the fact that a siphon ceases to work if it is placed under an air-pump bell and a vacuum made therein.

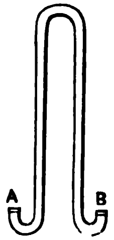
By this device the government school at West Point is supplied with water from the opposite side of one of the hills by which that station is encircled. When the height to which the water is raised in the short tube approaches 30 feet, the tube is liable to be gradually filled at the curve with air derived from the water; when this happens the siphon ceases to work. The air must then be pumped out of the bend, when the siphon again acts.

Large siphons like that described above are most easily filled or refilled, when necessary, by having a stopcock at each end, and another at the highest point of the bend. The operation of filling then consists in merely closing the cocks at the extremities, and pouring in water at the bend until the tube is full. Then closing the cock at the bend, and opening those at the extremities the flow is established. Large siphons have also been used for carrying sewage over intervening elevations, and for emptying ponds.

For the purpose of retaining the fluid in a small siphon, so that it may at all times be ready for use in a given liquid, both arms are sometimes made of the same length and turned up, as is shown in Fig. 34 at A B.

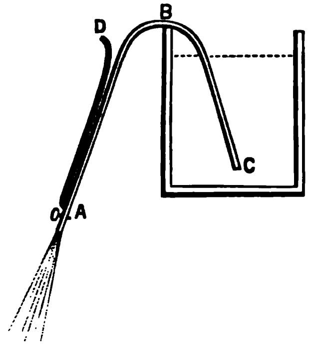
This form is very useful in removing the liquids covering precipitates, especially when a number of analyses are to be made. Siphons of glass are frequently used in the laboratory.

FIG. 34.



Retaining siphon.

FIG. 35.



Glass siphon.

When the liquid to be decanted is corrosive, the finger cannot be used to close the end of the instrument, as may be done in the case of water. Under these circumstances the form represented in Fig. 35 is employed, as follows: The end of the short arm, C, being placed in the fluid, the stopcock near the end of the long arm, A, is closed. The mouth being applied at D, the fluid is drawn over the bend, B, into the long arm. As soon as the fluid passes the line in the long arm at which it is on the same level as in the vessel, C, the siphon begins to draw. At this moment the mouth must be removed from D. Opening the stopcock at A, the fluid passes out, the discharge being under perfect control by the stopcock.

139. Flexible Siphon.—All kinds of material may be used in the construction of siphons. In filling electric batteries with dilute sulphuric acid, which has been made up in quantity, a piece of India-rubber tube answers admirably. The tube being dipped into the liquid, it fills; then bringing the upper end close to the surface, and pinching it together in order to close it, a portion of the tube is drawn over the side of the vessel, and a siphon is formed. On removing the pressure of the fingers, a flow is established into one of the battery jars. When the jar is full enough, the flow is stopped by again compressing the sides at the free end. By this method, without spilling or waste, the liquid may all be siphoned into the battery jars.

Where it is desired to establish a very slow flow, an ordinary cotton lamp-wick may be used. In the case of acids and other corrosive liquids, threads of asbestos, or a bundle of very fine capillary glass tubes may be formed into a siphon.

Fig. 36.

Intermittent siphon.

140. The Intermittent Siphon, as is shown in the figure, consists of a siphon, A, in which the short arm is curved and dips nearly to the bottom of a vessel, into which water is continually flowing. The long arm passes through the bottom. When the water rises to a sufficient height to fill the bend of the siphon, it is thrown into action, and the contents of the vessel pass off. The siphon then empties itself, and cannot act again until the fluid rises to the bend.

The intermittent springs which occur in nature, are often produced in this manner.

Valvular Apparatus for Raising Water.

141. Pumps and Valves.—These consist usually of a cylinder in which a piston moves, water or air tight. The direction in which the water is to flow is governed by valves, and according as these are arranged, we may have three kinds of pumps: 1st. *The suction or lift-pump;* 2d. *The force-pump;* 3d. *The compound pump*, which is both suction and force in its action.

The forms of valves employed are represented in the figures. At A, we have the ordinary form, viz., a disk of metal working on a hinge and covered with leather below to make it air tight. This is called a *clack valve.* B represents the *conical valve*, con-

Fig. 37.

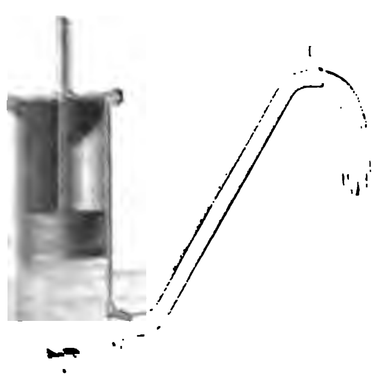
Valves.

structed as follows: To a conical opening a plug is fitted. The movements of the plug are limited and guided by a rod which passes from it through an opening in a metallic loop below. In a third form a disk of metal is pierced by a number of small holes, a strip of oiled silk stretches across these above, and rising or falling by its own elasticity, as the exhausting or compressing force is applied, opens or shuts the holes and forms a very perfect valve. This is the form usually employed in air-pumps and similar pneumatic apparatus.

T... . ...phon, the lift-pump depends
p... : ' its action. It contains two
mad. ...ase of the cylinder, B, and one
Both of these valves open
. ...n being at the bottom of the
. ...pwards, the valve in the pis-
...the cylinder opens, and as the
...essure of the air forces the water
... cylinder. Having reached the
. ...er, A, the motion of the piston is
. ...y the valve in the bottom of the
... ...e fall of the fluid is thereby pre-
...alve in the piston then opens,
... ... to descend, the charge of water
... ...assing through the opening in the
... ...next upward stroke the water in
... ...ifted higher and flows out of the
... top. At the same time the air
... more water into the cylinder.
...ted.
. ...ed to the bottom of the cylinder
...e applied to water at a considerable
. Theoretically, the height a pump
... is thirty-four feet; practically, it is
...rty feet.

... ...his form the piston is solid, as is
' The pump end, B, is placed in the

Fig. 39.



...rce-pump.

... ...wer part of the cylinder, C, is pro-
... ... from the side of the cylinder, and near

its bottom, a tube, D, passes, this is likewise closed by a valve. As in the lift-pump, both valves open upwards. The piston being at the top of the cylinder, on making a downward stroke, the valve, B, of the cylinder closes, that of D opens, and water flows through it. On making the upward stroke, the reverse takes place. The cylinder valve B opens, that in the tube D closes, and the water flows into the cylinder.

Usually an air or condensing chamber is attached to the exit tube. Its function is, by the compressibility and elastic properties of the air, to make the discharge of water continuous and relieve the machine from the shocks to which it would be submitted by the action of the piston on the slightly compressible water. The air chamber is virtually a gas spring, and serves the same purpose as any elastic spring.

The action of the heart is conducted on the same principle as a simple force-pump. It does not exert any suction action on the veins, but merely receives the blood from them and forces it into the arteries of the lungs or of the body.

In the third form of pump, the departure from that just considered consists in removing it to a distance above the fluid instead of placing it therein, a pipe being attached to the lower part of the cylinder. On making an upward movement of the piston, water is forced up into the cylinder by the pressure of the air. This constitutes the lift action, and is limited to thirty-four feet, as in the ordinary pump. The down stroke of the piston produces the force action as before described. The only limit to this latter movement is the strength of the apparatus and the power available.

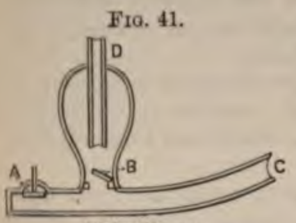
Fig. 40.

Decanting acids.

Another device, for the special purpose of forcing acids out of the carboys in which they are stored, has been recently introduced. It consists of a rubber cap or stopper, A, which fits the mouth of the carboy air tight. Through this two tubes, B and C, pass. Tube C goes to the bottom of the vessel. Tube B merely passes through the stopper; it terminates above in a small force-pump by which air is forced through B into the upper part of the carboy. The elastic force of this condensed air, acting on the surface of the acid in the carboy, forces the liquid through the tube C. By this contrivance, strong acids may be transferred without the escape of irritating fumes which so often attend the pouring of liquid from a carboy.

144. Hydraulic Ram.—When water is flowing freely from a stopcock, if we suddenly check its escape the pipe emits a sound as though it were struck. This sound originates in the momentum of the water moving in the pipe, and depends directly on the weight and rate of movement. In place of allowing the shock of the moving water to spend itself upon the pipe, let relief be offered by a small opening made in its side. If the stopcock be then suddenly closed, a fine jet of water will be seen to spurt from the opening to the height of many feet, and the clack or noise will disappear or be greatly lessened.

FIG. 41.



Hydraulic ram.

The hydraulic ram acts on the principle just described. In it the momentum of a column of water is applied to the raising of a portion of the column to a very great height, compared with that of the original source from which the water was derived. The machine consists of a tube, A C, two or three inches in diameter, and twenty or more feet in length, with a fall such as may be available, say three to ten or more feet. At A there is a metal valve, guided and controlled by a loop. The valve opens downwards. At B another valve gives access to the reservoir above, this opens upwards; D is the delivery tube.

When the water in the pipe C is at rest, the heavy metallic valve at A falls; through the opening thus made, the water in C passes, a flow is thus established, which soon becomes so strong that it raises the valve at A. The momentum of the column of water in the tube being thus suddenly checked, it relieves itself by passing into the pear-shaped chamber by raising the valve at B. The chamber is constructed to act like an air or condensing chamber. When the momentum of the column of water has been relieved by the passage of a portion into the condensing chamber, and the pressure on the valve B lessens, the return of the water is prevented by the closure of the valve B. The water in the tube C having come to rest, the valve A drops, the flow is reëstablished, again checked, again there is escape through B. This action continuing, sufficient pressure is finally accumulated in the air vessel to raise the water forced into it to a vertical height of a hundred feet or more above the ram through the tube D.

The hydraulic ram is especially adapted to supplying water to houses in the country. In old days the farmer built his house under the shelter of a hill to protect it from the blasts of winter. At the same time he assured himself of a supply of water, either from a spring or from a well. In these times,

when the merchant has accumulated money, he rears a palatial mansion in the country. Extended view of the surrounding landscape, and free exposure to every summer zephyr, are the things he chiefly seeks. An ample supply of water throughout the house is also essential. To obtain this on the hill summit, he must either construct tanks in the top of the building in which large quantities of rain water may be stored, or resort to pumping water from sources below the level on which his house is built.

Under these circumstances, if a sufficient flow of water is available, the hydraulic ram furnishes just what is needed. Once thrown into action, it works for months or even years without any attention. All that is necessary, is to protect it and its pipes from frost, by placing them deep in the ground. Sand or grit should also be prevented from gaining access to the interior, where it would wear the valves.

When the supply of water is not sufficient to work the machine continuously, the ram may still be used by constructing a cistern into which the water may run. Thus, in the course of twenty-four hours a sufficient quantity may be accumulated to run the ram for a number of hours or long enough to furnish a sufficient supply for the needs of the establishment. Under these circumstances, the storage cistern should be broad and shallow, not deep. The tube conveying the water from it to the ram, should have considerable fall and length, to gain as much momentum as possible. The greater the momentum, the greater the proportion of water raised. There is, of course, a limit to the shock the machine will stand, and the momentum must be kept within bounds. To reduce the hydraulic friction in the tube which conveys the water to the house, and which is often at a considerable distance, it should have a bore at least one inch in diameter.

Development of Power.

Next to air, water is the essential of greatest importance to the support of life. We cannot exist for more than a few moments without air. Deprived of water, life may be sustained for a few days. Without food, but with sufficient supply of water and air, we may live for many weeks.

To secure a sufficient supply of this important fluid, not only for the absolute maintenance of life, but also for the preservation of health, is a matter which commands the earnest attention of physicians. Therefore, it is, that we have presented at length all the ordinary devices for raising water, so that it may be available in sufficient quantity to secure the most perfect cleanliness.

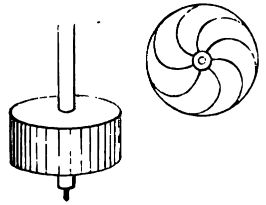
In cities, a liberal supply of water to each individual is of even greater importance than in the country. To meet this demand on the scale required, necessitates the exercise of considerable ingenuity. To raise a sufficient amount of water for the demands of a large community, means the expenditure of considerable power. This may always be obtained by the agency of steam, but if a sufficient flow of water is available, it is far more economical to press it into service as the source of power. The production of power from running water may be accomplished either by water-wheels or by the turbine.

145. Water-wheels. — These are of three kinds: 1st. The *undershot wheel*, in which the paddles of the wheel merely dip into the water of the stream as it flows past. 2d. The *breast wheel*, in which the water meets the wheel less than half way up its height, and then by means of a curved trough is kept in contact with the paddles. In this form, movement is produced partly by the impact of the water against the buckets, and partly by its weight as it passes down the trough and carries the buckets before it. 3d. The *overshot wheel;* in this the paddles are shut in on the sides and converted into buckets. The water being delivered on the top of the wheel, the buckets fill, and the action is entirely the result of the gravity of the water. For a given quantity of fluid this form gives the maximum of effect. It is, however, only applicable when the fall of water is of sufficient height. The breast wheel answers best with small fall and large flow.

By the use of one of these wheels, in a stream of water unfit for the purposes of domestic use, power may be generated whereby the water from springs at a distance may be raised.

146. The Turbine is a modification of the hydraulic tourniquet or Barker's mill (124). It consists of a drum closed at top and bottom. The interior of the drum is divided into a series of curved channels, which radiate from its axis. The water is admitted through the axis, which is hollow, and passes into the channels; by its reaction, as it glances off the curved blades, the drum is caused to revolve.

FIG. 42.



The turbine.

Various modifications of the above have been introduced. In some the blades revolve in the drum and so develop power. On a great scale, turbines are employed at Philadelphia for the purpose of raising the water used in that city.

147. The Centrifugal Pump.—The mention of this apparatus has been deferred until now for the sake of brevity of description. It is virtually a turbine reversed. By steam, or other power, the blades in the last described form of turbine are thrown into rapid revolution. Water is then admitted at the axis, it is caught by the revolving arms and hurled to the circumference, where the centrifugal force developed is so great that the water may by suitable means be made to rise in large volume to a moderate height.

This form of pump is admirably adapted to the purposes of drainage where the height to be surmounted is not very great.

Conveying, Storing, and Distributing Water.

Liberal supply of water to ancient cities was largely effected by means of open canals. Ruins of these still exist in connection with the gigantic cities of Assyria. Through their agency the hanging gardens of Babylon were supplied. Phœnicia, Jordan, and Egypt, also present innumerable ruins of canals, tanks, and aqueducts. So extensive were the aqueducts of ancient Rome, that they delivered a per capita supply of forty gallons a day to its enormous population. Some of these, and there were about twenty, were over forty miles in length. They pierced hills, and traversed valleys on lofty arches of brick, many of which are standing at the present day.

It is worthy of remark that a large part of the supply of water to Rome was consumed at the baths. The lack of material, other than earthenware, for the construction of pipes which could resist the pressure of a sufficient head of water, prevented its general introduction into houses. Hence arose the immense public baths, which were one of the chief places of public resort of those days. It is true, that in the palaces of the wealthy, water, and even fountains, were to be found in their courts, but nothing existed to be compared with the distribution throughout the lofty houses of our time.

Though the present supply to New York City is 95,000,000 gallons daily, which is about 80 gallons per capita, it is doubtful if the actual consumption for purposes of cleanliness is equal to that of ancient Rome. So great is the quantity of water used in New York for manufacturing purposes, and so little attention is paid to waste, that it is estimated that much less than one-half of the supply is actually used in domestic service. This would give less than forty gallons per capita, which, as stated above, was the Roman allowance.

148. Materials for Hydraulic Engineering.—The Roman aqueducts were built almost entirely of brick and hydraulic cement.

The perfect adaptation of these materials to the purpose to which they were applied, is demonstrated by the manner in which these water conduits have survived the ravages of time. Another advantage they present, in addition to that of imperishability, is that when hydraulic cement has once fairly set and hardened, it is as little acted upon by water as is brick itself. The water delivered by these aqueducts was, therefore, free from any impurity other than what it may have brought from the hills among which it was collected.

Not only was Rome great in its aqueducts, but its sewers also excelled those of modern times. Even at the present day hardly a sewer exists that can compare in size with the Cloaca Maxima, and not one surpasses it in workmanship.

The great advantage in the distribution of water possessed by modern engineers, is the adaptation of pipes, made of different metals, to this purpose. In ancient days there was little choice beyond tubes of earthenware cemented together, or rude wooden tubes made like boxes, or by boring stems of trees. These can only withstand moderate pressures. As the houses in those days were not very lofty, rarely being more than one story high, these simple contrivances sufficed for the circumstances under which they were employed.

The immense tubes of cast-iron now used as the water mains of great cities, are one of the recent contributions of science to the comfort and health of communities. The spinning of lead pipes is also a modern device, while the lining of leaden pipe with pure tin is an operation, the age of which is practically limited to the last twenty-five years.

Of the materials just mentioned, though iron is slowly acted on by water, the resultant oxides are innocuous. Recent improvements have, moreover, so reduced the price of small tubes of iron, that they are very generally driving out those of lead. The difficulty in the use of lead is its liability to cause contamination of water, by being slowly dissolved therein as a supercarbonate.

When water is very pure, the liability to the introduction of poisonous lead compounds is much greater than when it is impure, or contains sulphates of lime, soda, potassa, etc. Rain water, by virtue of its freedom from the salts we have mentioned, is far more liable to contamination than is spring or well water. The latter nearly always contains sulphates, which, uniting with the lead as soon as it is dissolved, form a coating of a perfectly insoluble sulphate of lead on the interior of the pipe. An old lead pipe will, therefore, deliver a purer water than one which is new. Advantage has heretofore been taken of this fact, and where a pure water was to be conveyed in lead tubes, they have been filled with solutions of sulphates, or of soluble sulphides,

and an insoluble lining of sulphate or of sulphide of lead formed.

The liability of the coatings above mentioned to fissure and split under varying changes of temperature and expose the lead, has resulted in the introduction of a process, whereby at the time the lead pipe is spun a lining of tin is also spun in its interior. If properly constructed, no pipe equals this in freedom from contamination in the water it conveys. The difficulties are: 1st. The liability to use impure tin, in which case a voltaic circuit is established between the alloyed metals and the water, and so poisonous metallic salts are introduced into the liquid in the tube. 2d. The difficulty of making joints in which two metals shall not come in contact with the water and produce the same result as if the tin was impure.

Of all substances that may be employed for the conveyance of water, glass is perhaps the best. Its brittleness has heretofore prevented its introduction. Perhaps, in the future, malleable glass, which is now only known as a curiosity of the laboratory, may find its practical application in the construction of water pipes.

149. Sewage in Houses is one of the questions in hygiene which is now a subject of general inquiry. We cannot put it more clearly before the reader than by a brief account of the development of this important factor in the construction of houses in New York.

When the Croton water was first introduced into the city, the streets were not generally sewered. It was, therefore, the common practice to prepare a receptacle for the waste water and sewage from water-closets, by knocking a hole in the bottom of the old rain water cistern, or by constructing a cesspool in the cellar. Though the water-closets of those days might have traps, the pipes from the basins and sinks were generally without them. Under these conditions, there were often two or three feet of putrefying filth in the cesspool, the noxious gases from which gained access, by the waste-pipes, to the bedrooms in all parts of the house.

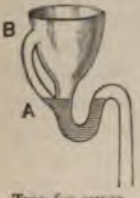
In time, the sewer system of the city was completed, and the abolition of cesspools became general, much to the advantage of the health of the community. In scattered localities, however, these foci of disease still exist.

Though the sewers were a great improvement, they did not accomplish all that was possible, because of faulty construction. In many localities the descent was not a continuous gentle decline, but here and there parts were horizontal and even slightly raised. The consequence was the formation of pockets,

which became foci of fermentation as bad as the old cess-pools.

To avoid the passage of the odorous sewer gas into the house, every basin or other outlet was then carefully trapped in the manner shown in the figure. By this device, a portion of the water flowing out of the basin was retained in the bend of the tube at A, and acting as a water valve prevented the access of sewer gas to the house. The pipe at B is the overflow.

FIG. 43.



Trap for sewer gas.

The difficulty with this *simple trap* was, that the waste-pipe being often of small diameter and of the same calibre as the trap, the water in passing down the descending portion of the waste-pipe, drew with it the last portions of fluid out of the trap (123), and thus, being emptied, it became useless. When a large quantity of water passed down the general waste, as when a bath was discharged, the exhaust in the pipe was often so great as to draw the water from all the traps in the house and leave it without protection from the access of sewer gas.

When waste-pipes have been in use for some time they become coated in the interior with a *deposit of organic matter*, which, undergoing putrefaction, gives out a most intolerable stench. It is from the pipes in the house rather than from the sewer, that the most abominable of the so-called sewer emanations arise. The deposit in question is the curdy material which may always be seen on the sides of a bath after use, especially when soap has been freely employed. It consists of epithelium with oily and saline excretions removed from the surface of the body by rubbing it with water.

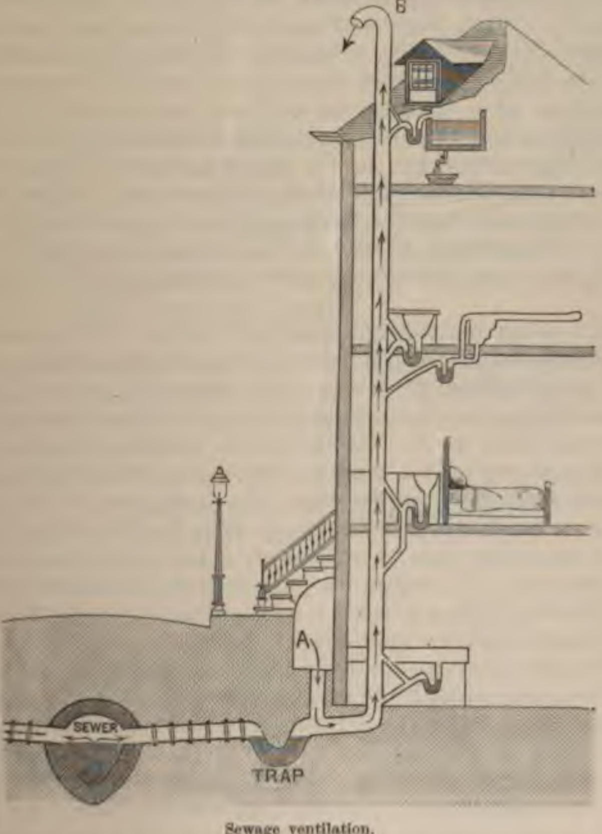
Soap also offers its share of contribution, especially if there be any lime salts in the water, which is nearly always the case. The manner in which it acts is, that whereas soaps with potash and soda are soluble in water, that formed with lime is insoluble and produces the curdy material which always appears when soap is used in a hard or lime water. This, in place of passing down the waste to the sewer, adheres in quantity to the walls of the waste-pipe. When persons recovering from exanthematous, or other diseases, use the bath, the germs of these are also entrapped in the curd, and lie in wait for such time as may bring them release and set them free for further action. Doubtless in the material in which they find themselves embedded, opportunity is offered for the development of *contagion spores* in innumerable hosts.

The prevention of the formation of these accumulations in waste-pipes has been one of the problems of modern hydraulic science. It has been found that if a circulation of air can be

kept up in the tubes, the deposit will dry, and peeling off pass into the sewer and be disposed of. To secure this *ventilation* the waste-pipes must have sufficient size, the smallest being at least two inches in diameter of bore. The larger tubes should have a bore of six inches. They should be made of iron pipe, the joints of which are carefully closed with lead.

In the adjoining figure a simple plan is given of one of the best arrangements of waste-pipes to secure ventilation thereof.

FIG. 44.



Sewage ventilation.

From the sewer the drain should rise gently until it approaches the house. Within a few feet of the foundation wall a trap should be formed. This will prevent any passage of gas from

the sewer. Just as it leaves the trap, a branch, five inches in diameter, should pass vertically upwards and communicate with the external air as at A. On entering the house the main waste-pipe should pass at an incline along one of the side walls of the cellar to its chief connections with the house pipes and leaders from the roof. Being exposed throughout its whole length, any leak or imperfection may be at once detected and remedied; careless workmanship is also easily discovered.

The slight difference in expense of this method, over that of laying earthenware pipes under the cellar floor, is not worthy of consideration, when compared with the increased security offered. So carelessly is work done by the workmen of our day that it is often found, after examination, that these hidden pipes have been partially plugged with various materials when they were laid. At other times, no attention is paid to the preservation of a continuous decline, but shallow pockets in which solid sewage accumulates, are formed at more than one position. In every case many and frequently all the joints are open, and without the first vestige of cement. What wonder, in the latter case, that the leakage from the waste-pipes suffices to keep the subsoil of the cellar damp with liquid sewage, and suited to the development or propagation of various diseases.

At the most convenient position, which will generally be some twenty feet from the rear of the building, the waste-pipe should pass vertically upward, out through the roof, and to a height of five or six feet above the same. Here it should terminate in an elbow at B. In its whole length, from A to B, the waste-pipe forms an air siphon, the short arm being at A, and the ascending portion forming the long arm. An upward draught is established in the long arm by virtue of its greater warmth, as is the case in a chimney-shaft. Its course is shown by the arrows. To maintain the draught, air enters through the short arm at A, and so the main drain-tube is freely ventilated throughout its whole extent.

With a free current of air in the main drain, the lateral pipes of communication with the basins and closets may be sufficiently ventilated to secure the drying and removal of the deposit, when water is not passing along them. At the same time, free communication by the vertical pipe with the external air, and its great diameter, prevent the establishment of exhaust of any consequence upon the traps, and they are not emptied. If with such an arrangement as this, the water-closets and traps are, from time to time, freely flushed out with a liberal supply of water, the chances for the development of noxious gases and germs are reduced to the minimum.

150. Utilization of Sewage.—Though the utilization of the organic matter in the sewage of great cities has received little or no attention in this country, various methods have been adopted in Europe. Among these, the simplest is the direct use of the sewage water for the purposes of irrigation. Many devices have also been suggested for the precipitation of the organic material from the immense mass of liquid in which it is suspended. Of these, the most satisfactory is that by the superphosphate of magnesia, which not only throws down the organic matter, but also adds to it the phosphate so necessary for the formation of a first-class fertilizer.

The *method by magnesian phosphate* consists in collecting the sewage discharge of a day in an immense tank. As it flows in, it receives its small proportion of magnesian phosphate. It is allowed to stand a day or so for the precipitate to settle. Meanwhile the sewage is directed into another tank, and so none is lost. When the solid matter in the first tank has settled, the clear water is discharged, a new supply admitted, and a second deposit forms. After the deposits have gained sufficient depth, they are removed, dried, and packed for use. Doubts have, of late, been raised as to the wisdom of the use of these deposits on account of their liability to contain germs of diseases, and to favor their propagation.

151. Marsh Draining and Malaria.—In closing the subject of hydraulics it seems proper that a few lines should be devoted to the subject of the drainage of marshes, in connection with the development of malaria.

Experience has shown that malarial poison is generally most troublesome in those years in which there has been a deficiency in the rainfall. The common explanation given of this, is that under these circumstances the water in marshes having fallen below its normal level, the black slime of organic matter forming their beds has been exposed to the strong heat of the summer sun, and the malarial emanations thereby increased in quantity and intensity. Low water in the great rivers of the West is also followed by increase in and aggravation of malarial troubles.

Development of malaria likewise occurs from the mere upturning of earth which has been undisturbed for many years. Of this Southern New York has given evidence, in the five great waves of malaria that accompanied the construction of the Croton Aqueduct, the building of the Harlem, Hudson River, and New Haven railroads, and of the Fourth Avenue Tunnel. Even the mere ploughing of an old orchard is not without its effect. In the latter case, if the upturning is done

late in the fall, and the earth exposed to winter frosts, there is much less probability of malarial emanations, than if the earth is turned late in the spring or during the summer.

These facts show that when it is deemed proper to drain a marsh, arrangements should be made to carry the operation out as late as possible in the fall of the year, and still leave sufficient time to give the soil an upturning before it freezes. Thus, the winter air, charged as it is with ozone, may have an opportunity to come in contact with the material from which malarial emanations arise, and exert its destructive action upon it.

In no case should a marsh be either drained or its bed exposed to the intense heat of the summer sun.

SECTION IV.

GASEOUS MATTER.

CHAPTER XI.

GENERAL AND SPECIAL PROPERTIES OF GASES.

General observations regarding gases—Form not fixed—Gases have weight—Reunite behind dividing solid—Hypothetical constitution of gases—Vapors—Determination of density—Relation of density to combining equivalent in gases—Compressibility—Expansibility—Elastic force—Elasticity.

152. General Observations Regarding Gases.—As water was taken as the type for the examination of the properties of liquids, so air offers a type for the examination of the gaseous form of matter. The study of the physical, in contradistinction to the chemical properties of gases, is called *pneumatics*. It deals with the weight, pressure, elastic force, and similar properties of this form of matter. In illustration of the leading peculiarities of gases and their contrast with liquids, we place before the reader the following extracts from the work of Dr. Arnott.

"While the ancients had that vague notion of air which made them apply to it, almost indifferently, the names of *air*, *ether*, *spirit*, *breath*, *life*, they never dreamt of making experiments upon it, with a view to prove its identity with grosser matter. And one of the most interesting parts of the history of man's progress in knowledge is that which tells how the light gradually dawned upon this subject. Galileo was the first to conclude that air made a definite pressure upon things at the surface of the earth—as in forcing water into the exhausted barrel of a common pump; Torricelli and Pascal proved that this was caused by its weight, and even attempted to estimate the height of the aërial ocean; Priestley, Black, Lavoisier, and others discovered that air or gas was of different kinds—that, for instance, one kind, called oxygen, could unite with a metal,

so as to increase its bulk and weight, and produce a compound of totally new qualities; and at last chemists analyzed the atmosphere itself, and proved it to be a mixture of two distinct substances. The nature of gases has now been so thoroughly investigated that they can be manufactured, measured, and operated upon as readily as the more palpable liquids and solids.

"The suspicion being once excited that air is as much a material fluid as water, only less dense by reason of a greater separation and repulsion of the particles, it is easy to confirm the analogy by reference to familiar facts. Thus, as a leathern bag when opened out under the surface of water becomes full, and, if its mouth be then tied, cannot afterwards be pressed together; so a bladder, opened out in air and then closed, remains bulky and resisting, and forms what is called an air-pillow. The motion of a flat board is resisted in water; the motion of a fan is resisted in air. Masses of wood, sand, and pebbles are rolled along or floated by currents of water; chaff, feathers, and even rooted trees are swept away by currents of air. There are mills driven by water; and so there are mills driven by the wind. Oil set free under the surface of water, or placed there in a bladder, is buoyed up to the surface; hot air or hydrogen gas placed in a balloon, is buoyed up in the air. A fish moves itself by its fins and tail in water; a bird moves and directs itself by its wings and tail in the air; and as on emptying the water from a vessel in which a fish swims, the creature falls to the bottom, gasps a few moments, and dies; so, on exhausting the air from a vessel in which birds or butterflies are enclosed, their flapping wings are powerless to support them, and if the experiment be continued they soon die."

153. Form not Fixed.—As was the case with liquids, the form of gases is not fixed, but is determined by that of the vessel containing them. They in this, and in many other respects, resemble liquids, as we have seen above. A very good description of gases might be summed up in the statement that their characters and properties are merely great exaggerations of those of liquids. Solids afforded numerous special properties, in addition to the general characters which they possess in common with liquids. In gases, the variety of these that we can distinguish is greatly reduced. As we pass to rarer and rarer forms of matter, there is greater and greater simplicity of properties. As far, at least, as regards their physical characteristics, substances chemically different approach nearer and nearer to each other. The properties which were general in solids and liquids, are the chief ones presented by gases, but they have become so

exaggerated that they in reality are the special properties of this form of matter, and as such we shall treat of them.

154. Gases have Weight.—In common with solids and liquids, and notwithstanding their exceeding levity, gases possess weight. Of this a demonstration is offered by direct experiment. In Fig. 45, A represents a flask with a capacity of one hundred cubic inches. The mouth is closed by a stopcock B. Attaching the flask to one arm of a balance, it is carefully counterpoised. It is then removed from the balance, and brought into connection with an air pump by the screw on the stopcock. As water might be pumped out of the flask, so the air is removed by the air-pump. When the exhaustion is complete, the flask is again attached to the arm of the balance, when it will be found to have lost weight. Adding sufficient weight to the lighter, or flask arm of the balance, until equipose is restored, it will be found that about thirty-one grains are required for that purpose.

Fig. 45.

Weighing gases.

One hundred cubic inches of air, therefore, weigh thirty-one grains. Comparing air with water, *the latter is seven hundred and seventy-three times the heavier.* Among themselves gases show a far greater variation in weight than either solids or liquids. 100 cubic inches of hydrogen, which is the lightest, weigh 2.14 grains, while 100 cubic inches of hydriodic acid gas weigh 146 grains, or a ratio extending from one to sixty-five. In the case of ether and mercury, relatively one of the lightest and the heaviest of liquids, the variation is from one to twenty. If we exclude mercury and confine it to non-metallic liquids, of which sulphuric acid is one of the heaviest, the proportion diminishes to about one to a little more than two. In metals it is greater than in liquids, the difference between lithium and platinum being one to thirty-seven. It is true that in the case of solids, the extent of variation might be increased by comparing cork, or other organic bodies, with platinum, but that would hardly be correct, since such organic substances owe their lightness chiefly to the air entrapped in their structure.

Since gases possess weight, it follows that, like fluids, they exert pressures within their own volume. The amount and character of these pressures we shall examine later on.

155. Reunite behind Dividing Agent.—Since all liquids are visible, there is no difficulty in the verification of this fact. The invisibility of air and the ordinary gases, renders it more diffi-

cult of demonstration. If, however, we subject to experiment some gas which is visible by virtue of its color, we then find that gases possess this property in a higher degree than liquids. In demonstration of this take a large bottle of colorless glass, A, place in it a beaker with some copper trimmings, B, and on these pour two or three drachms of nitric acid; red fumes of tetroxide of nitrogen quickly fill the vessel. Then pass into it a rod, D, with a circular disk, C, attached to its extremity. No matter how quickly the disk is made to traverse across the jar, the red gas closes in behind it instantly, even though the disk is moved with the flat surface forward. Now pass the disk through water in the same manner, flat surface forward, though the water closes behind it there is a short distance where no water is present. We thus find how much more perfect the property of reuniting is in a gas than in a liquid.

FIG. 46.

Reunite behind dividing agent.

Though we cannot see this movement of closure in air on account of its invisibility, it is very apparent when sufficient velocity is given to the dividing body. A rifle-shot, for example, in its passage emits a peculiar noise caused by the clashing together of the air in the track the shot has ploughed through that medium. Even so impalpable a body as lightning, in its passage through the atmosphere, gives evidence of the same fact; the thunder that attends it being produced by the violent closure of the air it has divided in its course.

156. Hypothetical Constitution of Gases.—The *Kinetic* (κινέω, to move) theory of Clausius, as stated by Crookes, is as follows:

"In gases the molecules fly about in every conceivable direction with constant collision and enormous and constantly varying velocities, and their mean free path is sufficiently great to release them from the force of cohesion. Being free to move, the molecules exert pressure in all directions, and were it not for gravitation they would fly off into space. The gaseous state remains so long as the collisions continue to be almost infinite in number and of inconceivable irregularity. The state of gaseity, therefore, is preëminently a state dependent on collisions. A given space contains millions of millions of molecules in rapid movement in all directions, each molecule having millions of encounters in a second. In such a case the length of the mean free path of the molecules is exceedingly small, compared with the dimensions of the containing vessel, and the properties which constitute the ordinary gaseous state of matter which depend upon constant collisions are observed."

In solids, as we have seen, the cohesive or attractive force is in excess of the repellant; in liquids these two forces are nearly evenly balanced; in gases the repellant is enormously in excess of the attractive force, so that gases may be said to possess scarcely any cohesive force at all.

157. Vapors.—Gases like hydrogen and oxygen were formerly thought to be permanently gaseous in their nature. No pressure or intensity of cold to which they could be submitted possessed the power of changing their state. Improvements in the methods of manipulation have, however, shown that the most refractory gases may be compelled to assume the liquid and even the solid form. The old division of this group of bodies into permanent gases and vapors, therefore, no longer actually exists; nevertheless, the convenience attending its use is such that it will doubtless be retained for some time.

A gas may, therefore, be defined as an aërial body which cannot be easily forced to assume the liquid state.

A vapor, on the contrary, is an aërial body which may be easily made to assume the liquid state by moderate reduction of temperature or increase of pressure.

Under these definitions, bodies like hydrogen, oxygen, carbonic acid, are dealt with as gases, while steam is a vapor.

As the temperature of a vapor approaches the point at which it tends to assume the liquid state, it does not contract and expand regularly. At a certain distance from this point all vapors obey the laws of contraction and expansions for gases. When, therefore, their specific gravity or other important property is to be determined, it should be at a sufficient distance from their point of liquefaction to insure accuracy in the results.

158. Determination of Density.—The method is essentially the same as that for the determination of density of liquids by the specific gravity bottle. The great variations which the volume of a gas undergoes from slight causes, require a number of corrections to be made in carrying out the process as thus simply stated. By the method of Regnault some of these may be avoided. It may be briefly described as follows: Two globes of thin glass of the same size and about a gallon in capacity are taken. One of these is hermetically sealed, and suspended from one arm of the balance. It acts as a volume counterpoise to the other globe which is to be employed for experimentation. Since both globes will expand and contract at the same rate under variations of temperature and pressure, their changes will balance each other, and these sources of error are consequently eliminated from the operation.

The experimental globe is filled with air or with the gas at zero centigrade, the melting point of ice. This is done by

placing it in a vessel of ice, then by means of a three-way cock it may be connected either with an air-pump or with vessels holding purified air or gas.

The weight of the empty globe is first determined, the air having been removed by as perfect an exhaustion as possible. Air which has been purified by passing it through tubes containing suitable reagents and dried by tubes of sulphuric acid and chloride of calcium, is then passed into the empty globe until the interior and exterior pressures are equal. All exterior moisture is carefully removed, and it is then weighed. The increase represents the weight of air it contains at 0° C. and the then prevailing barometric pressure.

Again the globe is placed in the ice and exhausted. The gas to be examined is introduced after proper purification and drying. To insure removal of the last traces of air, the globe is connected with the air-pump and the gas removed by exhaustion. In this manner the last traces of air are, as it were, washed out, and it is weighed. It is then refilled with the dried gas, removed from the ice bath, the exterior carefully dried, and weighed. The increase in weight represents the weight of the gas at 0° C. and the prevailing pressure. From these data the specific gravity of the gas may be computed in the same way as for solids and liquids. All results are reduced to the pressure of 760 millimetres, and temperature of 0° C.

159. Relations of Density to Combining Equivalent in Gases.—The determination of the correct densities of gases and vapors is of the utmost importance on account of the close relationship existing between the specific gravities and the atomic or the molecular weights of these bodies.

When a table of densities is constructed with hydrogen as its basis, this relationship is at once evident, as will be seen below, the figures either being identical or multiples of each other. The fact of this relationship of specific gravities and atomic weights, or combining equivalents to each other, has enabled chemists to make more accurate estimations of the combining equivalents of many elementary substances.

Substance.	Molecular formula.	Molecular weight.	Atomic weight.	Sp. gr. H=1.	Sp. gr. air=1.
Hydrogen . .	H_2	2	1	1	.069
Chlorine . .	Cl_2	71	35.5	35.5	2.460
Oxygen . . .	O_2	32	16	16	1.108
Nitrogen . .	N_2	28	14	14	.970
Steam . . .	H_2O	18	..	9	.625
Ammonia gas. .	NH_3	17	..	8.5	.589
Carbonic acid gas .	CO_2	44	..	22	1.524
Alcohol vapor .	C_2H_6O	46	..	23	1.593
Air	....	..	..	14.44	1.000
Ether vapor . .	$C_4H_{10}O$	74	..	37	2.557
Chloroform vapor .	$CHCl_3$	119.5(?)	..	60.5(?)	4.181

160. Compressibility.—Take an ordinary syringe, consisting of the cylinder or barrel A, in which the piston C moves without leakage. Close the outlet B with a plug of wax or a cork, or even with the finger. Between the piston C and the outlet B a column of air will then be enclosed. On applying pressure to the piston by its rod at D, this column of enclosed air will be with ease reduced in volume, as is the case with liquids; therefore, gases are compressible. They, however, differ in this: that whereas water, the type of fluids, shrinks one-twenty thousandth of its volume for an atmosphere of pressure, air diminishes to one-half.

FIG. 47.

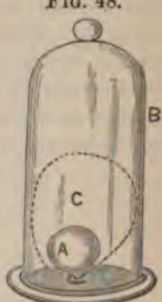
Compressibility of gas.

161. Expansibility.—The wonderful compressibility of gases, of which evidence has been given in the last article, would naturally lead us to expect a parallel extent of expansion on diminution of pressure. That this is the case is shown by the experiment (19).

The expansibility of gases is one of their leading peculiarities. It may be said to be almost infinite, for a gas will fill a space of any size we offer it.

162. Elastic Force of Gases is in reality another term applied to expansibility. If a small rubber sack, A, be partly filled with air, its mouth tightly closed, and placed on the air-pump plate under a bell-jar, B, on exhausting the air from the bell the rubber bag expands until it occupies the space represented by the dotted line, and may even be made to appear to fill the entire jar.

FIG. 48.



Elastic force of gas.

The rationale of the action is as follows: According to the kinetic theory of gases (156), their molecules are flying about in all directions; they are, therefore, battering and pressing against the interior walls of the bag. So long as the pressure of the air is not removed, it counterbalances the pressure in the interior of the bag. The moment the exterior pressure on the sack is removed, the interior pressure becomes evident, and expansion is the result; this continues until the interior and exterior pressures are again in equilibrio.

An interesting illustration of expansion may be performed with an egg. In the large end of an egg there is a bubble of air. A small opening is made in the narrow end of the egg and it is stood in a wineglass under an air receiver. On

exhausting the receiver, the contents of the egg pass out into the wineglass, being expelled from the shell by the elastic force of the bubble of air at the wide end. Restoring the pressure of the air the contents of the egg are returned to its shell.

This *elastic force* of gases, which is perhaps their most characteristic property, has caused them to pass under the name of elastic fluids, in contradistinction to ordinary fluids like water. It is not to be confounded with the elasticity which gases possess in common with liquids proper.

163. Elasticity refers to the power of returning to original volume when the cause of disturbance is removed and the original conditions restored. Both gases and liquids possess this property in a marked degree. Indeed, it may be said to be absolute, and the direct consequence in both cases of the mobility of their molecules.

The experimental demonstration of the elasticity of gases may be derived from the arrangement employed in article 160, for on removing the pressure on the piston it at once returns to its original position. In like manner, articles 161 and 162 both furnish evidence of this fact, though in a different way, the return to original volume in this case being produced by restoration of original pressure.

Owing to the elasticity of gases pressure may be suddenly transmitted through them to considerable distances. An illustration of this fact may be shown by suddenly increasing the pressure in the gas-pipes of a building, as by blowing into them the lights are all immediately extinguished. A method of telegraphy founded on this property of the air, is now employed in the transmission of signals on ships. Its great advantage is its certainty, since it is less liable to get out of order than other methods of signalling. The tambours of Marey are also based on this property of air.

CHAPTER XII.

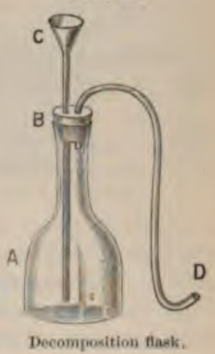
PNEUMATIC APPARATUS.

Generation of gases—Collection at pneumatic trough—Pouring—Faraday's tube receiver—Gases arrange themselves according to density—Collecting gases by displacement—Washing and drying gases—The aspirator—Compression air-pump—Life and condensed air—Exhaustion air-pump—Life and rarefied air—Mercury pump—Bunsen's filter pump—Limit of vacuum—Vacua by chemical agents.

164. Generation of Gases.—The demonstration of many of the physical properties of gases requires that we should have at hand one lighter and one heavier than air. For the first, hydrogen will answer; for the second, carbonic acid gas. As a rule, gases are generated either by the action of heat on certain substances placed in glass retorts, or by the action of acids on suitable materials. In either case, the methods of collection, storage, and manipulation are the same.

For ordinary purposes of experiment the simple apparatus shown in the figure may be used for the generation of hydrogen or carbonic acid. It consists of a bottle, A, with a tolerably wide mouth, B, closed by a rubber or cork stopper, which fits air-tight; this is the decomposition bottle. Through the stopper a tube passes to the bottom of the bottle, and terminates above in a funnel-like expansion, C. This is called the supply tube, by it the acid is to be added as required. A second tube, D, bent in the manner shown, also pierces the stopper, through which it just passes. By it the gas escapes as fast as it is generated. It is, therefore, called the escape tube, and serves to convey the gas to the apparatus for collection.

FIG. 49.



Decomposition flask.

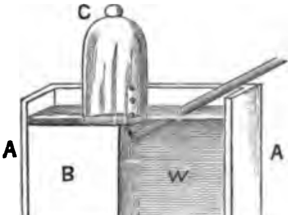
For the generation of carbonic acid gas, a few fragments of Italian marble or of chalk are placed in the bottle, enough water is added to cover them, the stopper is then put in position, when the lower end of the supply tube should dip under the surface of the water. Sulphuric acid is then added, a little at a time, by the supply tube. As it reaches the water and comes in con-

tact with the marble, effervescence is produced, carbonic acid gas being evolved. It passes off by the escape tube. When the effervescence decreases in vigor, more of the acid is to be added by the supply tube. At the beginning of the operation, the bottle is filled with air, it therefore follows that if we desire to obtain the carbonic acid comparatively pure, enough must be allowed to pass off to expel all the air from the bottle. A quantity twice the capacity of the bottle will answer.

If hydrogen is to be made, the apparatus is emptied, cleansed, and strips of zinc are substituted for the marble. The remainder of the operation is conducted in the same way as for carbonic acid gas. As hydrogen is lighter than air, it is necessary to use a larger quantity in the removal of the air from the bottle. About three or four times its volume are generally required. Great care must also be taken not to allow a flame to come in contact with the mixture of air and hydrogen, as it escapes from the tube D, or an explosion attended by serious consequences may occur.

165. The Pneumatic Trough.—The collection of gases may be conducted in three ways. 1st. By reception in an exhausted vessel, as described in the method for taking specific gravity. 2d. By collection over a liquid. 3d. By displacement of air. For the second method the apparatus known as the pneumatic trough is required. It consists of a water-tight box, A A, represented in section in Fig. 50. The side and half way across is occupied by the shelf B, on which the bell-jar C stands. The remainder of the trough, W, is called the well. Sufficient water is poured into the trough to fill the well entirely, and also to cover the shelf to a depth of a couple of inches.

Fig. 50.



Pneumatic trough.

When a gas is to be collected, a jar is filled with water in the well, it is then turned with the mouth down, and without allowing the mouth to rise above the water, it is placed on the shelf, as is shown in the figure. Thus arranged, the jar remains filled with water, and if it has been properly filled is free from air, except so far as any may be dissolved in the water. The cause of the suspension of the water in the jar is, as we shall find hereafter, the pressure of the atmosphere upon the surface of the water in the tank.

The collection of the gas from the generation vessel is now accomplished by merely passing its escape tube, D, under the

mouth of the bell-jar, as it rests on the shelf of the trough. The gas bubbles rising through the water accumulate in the jar without mingling with the air, and the operation is continued until the jar is filled. The delivery tube is then placed under the mouth of a second jar, and the collection continued in the same manner.

When the gas to be collected is very soluble in water, as for instance ammonia gas, mercury may be substituted for water. In this case, the apparatus must be much smaller and much stronger, on account of the great expense and weight of that liquid. The tube apparatus is very convenient for this purpose (167).

166. Pouring Gases at the Trough.—The pneumatic trough also enables us to manipulate gases in almost any manner that we may desire. Suppose that it is required to transfer a measured portion of gas to another jar, the operation is conducted as shown in the figure at A. A small graduated bell is filled with water, and held in the position shown at A, with its mouth under the water in the trough. The large bell containing the supply of gas is then immersed completely and its mouth inclined under that of the small bell until the gas passes in bubbles from the larger to the smaller jar. This upside down pouring through water is continued until the line of the gas in the small bell coincides with the desired line of the scale marked thereon.

FIG. 51.

Pouring gas.

If the gas is to be measured in a narrow bell, a funnel may be used to facilitate the filling of the tube, as it would be to assist in filling it with fluid. The only difference is that in this case the operation is reversed or upside down, as is shown at B in the figure.

167. Faraday's Tube Receiver.—Gases may be experimented with on the small scale by the instrument known as the tube receiver of Faraday. It consists of a test-tube about ten inches in length and three-fourths of an inch in diameter. This is bent in the manner shown at A B in Fig 52. The whole length of the tube is filled with water. It is then suspended with the closed end upwards. The air pressing on the surface of the water in the open end A of the short arm, retains the fluid in position in the long arm B. Passing the delivery tube D of a gas generator into the short arm to the bend, as fast

as the gas is evolved the bubbles pass into the long arm and are collected at B, the displaced water dropping into C.

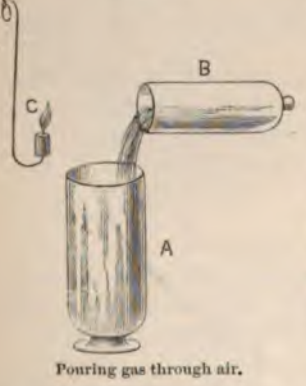
The short arm of this arrangement may be used as an experimental vessel, while the long arm serves as a reservoir. The manipulation in this case consists in filling A completely full of water. The mouth of A is then closed with the thumb, and the apparatus so inclined as to fill the short arm with the gas collected in the long arm. Uncovering the mouth of A, by removing the thumb, a piece of wood bearing a spark, or paper imbued with any liquid test, may be applied to the gas it contains. For a second examination the short arm is again filled with water; the gas it contains is thus displaced. It is then closed by the thumb, and the apparatus inclined to fill A with a second charge of gas, to which some other test, as paper moistened with a lead salt, may be applied. Thus test after test may be applied, until the gaseous contents of the instrument are consumed.

FIG. 52.

Faraday's tube receiver.

Many examples of this form of apparatus are offered in utensils or articles in common daily use, though in these cases it is generally water rather than gas that is stored. Among such examples we may mention the water tube of Mason's hygrometer; the bottles for holding ink, gum, and for the water supply of bird-cages. The supply tank of many lamps is also constructed on this plan.

FIG. 53.



Pouring gas through air.

168. Gases Arrange Themselves According to Density.—As is the case with liquids, gases show a tendency to arrange themselves according to their specific gravity, the lighter floating on the heavier. That this is the case is demonstrated by the experiment delineated in Fig. 53, in which A is a large jar filled with air, and B a small one containing carbonic acid. Inclining the mouth of B over that of A, and manipulating the jar exactly as though water were being poured from the smaller to the larger, the carbonic acid gas will flow from B into A. That this has really happened is readily proved by examining the contents of the jars with

a candle-flame C, when it will be found that it is extinguished in A when it reaches a certain depth, and continues to burn in B. Since carbonic acid gas does not support combustion, it is shown that it has flowed from B into A on account of its weight, and has expelled the lighter air from the jar.

Fig. 54 represents another form of the same experiment. A B is a trough six feet in length, with sides six inches high.

FIG. 54.

Weight of carbonic acid gas

A row of candles is placed along the bottom about a foot apart. The trough is inclined with one end, A, resting on the floor and the other, B, supported on a stool. The candles being lighted, a large jar of carbonic acid, C, is poured into the trough at its upper end. The gas at once passes down the trough as water would do, putting out the flames in its course, and spreading on the floor extinguishes other flames that may be within its reach.

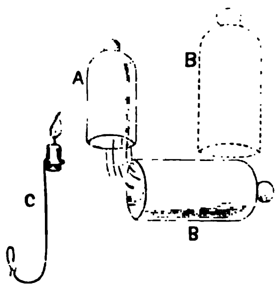
This tendency of carbonic acid to collect in low places is at times the cause of loss of life. In mines, caves, and wells, it not unfrequently happens with disastrous results. In breweries also, where it is generated in large quantities during the process of fermentation, it often accumulates to such an extent in the vats that workmen have lost their lives by breathing its poisonous fumes.

If an attempt is made to repeat the experiment shown in Fig. 53 with hydrogen gas, it will be found that the vessel A does not contain a trace of that gas. To determine what has become of it, let the experiment be repeated with the vessels arranged as shown in Fig. 55, in which A is suspended mouth downwards, and B is brought alongside, in the position shown by the dotted lines, and then gradually tilted to the horizontal. On examining A with a candle-flame C, an explosion will result, showing that the hydrogen has by its inferior specific gravity floated upwards into the jar A, and displaced the air with which it was filled.

In these experiments the hydrogen and carbonic acid gas retain their positions for only a short time. By degrees either

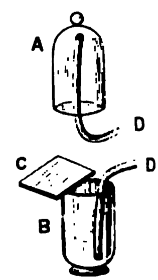
of these gases intermingles with the air, by virtue of the process called diffusion. This we shall study hereafter in connection with other forces.

FIG. 55.



Hydrogen poured upwards.

FIG. 56.



Collection by displacement.

169. Collection of Gases by Displacement.—The experiments we have described explain the third method by which gases may be collected. This is known as the method by displacement. If the gas is lighter than air, the jar in which it is to be collected is suspended in the manner shown at A, Fig. 56; the delivery tube D is then passed to the upper part of the jar. The gas as it accumulates in the jar displaces the air, until finally it is completely expelled.

If the gas is heavier than air, the jar is then arranged as is shown at B, Fig. 56, with its mouth upwards, and the delivery tube D passes to the bottom. The mouth of the jar may be closed by a sheet of glass or paper, C.

The method by displacement is especially applicable to the collection of gases like ammonia or hydrochloric acid, which are very soluble in water. They cannot be obtained quite free from contamination with air, on account of the tendency to diffusion of which we have spoken; but they may be thus collected for purposes of examining or demonstrating their leading properties.

170. Washing and Drying Gases.—The separation of gases from finely divided solid matter, or from fluid or aërial substances with which they may be contaminated, is accomplished by means of the washing bottle and drying tubes.

The washing bottle consists of a wide-mouthed bottle, A. The mouth is closed by a cork, through this a tube, B, passes to the bottom of the bottle. It may be the continuation of the delivery tube of a gas generator, or it may be connected therewith by a piece of rubber tube. In the bottle A, water is placed, through this the gas is obliged to pass in bubbles, these

are submitted to the action of the water, and any dust-like particles, vaporous mist of acid, or other impurity is washed out. By the use of a suitable liquid in the washing bottle, any gas soluble in such liquid may be separated from one which is insoluble, and a purified gas obtained.

In place of a bottle, a tube of the shape delineated at C may be used. It is called a U tube. The bend of the tube is to be occupied by the liquid, when it is used for the purpose in question. In Fig. 57, the U tube and bottle are combined. Various modifications of this tube are employed. Among these we may mention Liebig's carbonic acid bulbs and the ammonia tube.

FIG. 57.

Washing bottle.

For the purpose of drying gases, the U tube is filled with pumice which has been heated red hot to expel all moisture, and then soaked in sulphuric acid; it is shown at C. Sometimes it is filled with solid porous chloride of calcium. Either of these substances has an intense affinity for water, and will abstract it from gases as they pass over or through them.

The proper conduction of these washing and drying operations requires that the gas should pass slowly, otherwise the action is only partial. To secure complete action, a number of bottles or tubes should be employed, and the incomplete action of the first supplemented by that of others.

171. The Aspirator is an apparatus used for drawing air or other gases through systems of tubes or bottles, in which they may be submitted to the action of various reagents. It consists of a large bottle, A, with a capacity of a gallon or more. It is to be filled with water. On opening the stopcock at B, the water flows out into C. As the water passes out, air enters at the mouth of the bottle. The mouth is closed by the cork A, through which a tube passes. If this is brought in communication with a U tube, as represented at D, the air in its course will be drawn through D, and submitted to the action of any agents that may be placed therein.

FIG. 58.

Aspirator.

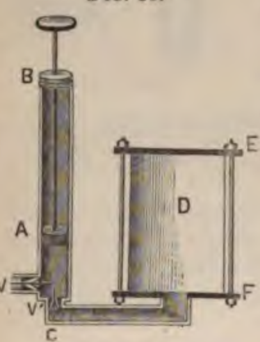
The aspirator is used in the examination of air. It is also of service in ultimate organic analysis, for the purpose of withdrawing the last traces of gas from the combustion tube and other parts of the apparatus.

For its action this instrument depends upon the pressure of the air, which forces its way into the bottle as the water runs

out. If the train of tubes through which the air must pass to reach the aspirator bottle contain much liquid, it may be necessary to attach a vertical tube one or two feet in length to the stopcock B. A long column of water being thus called into action, the pressure will be increased and the resistance overcome. See (123).

172. The Compression Air-pump.—It is necessary for the examination of the properties of air and other gases that we should describe the forms of pumps employed for purposes of compression and exhaustion. The compression pump resembles an ordinary force pump in its structure and action (143). In Fig. 59, A is the solid piston moving in the cylinder A B. Below A, a lateral tube with a conical valve opening towards the cylinder gives ingress to air or other gas which is to be made the subject of experiment. At C there is another tube, also closed by a valve which opens outwards from the cylinder, and gives egress to the gas when the piston is forced downwards. Each upward movement of the piston draws gas in through V, while the downward movement forces it out through V′; the valves in each case preventing its return.

FIG. 59.



Compression air-pump.

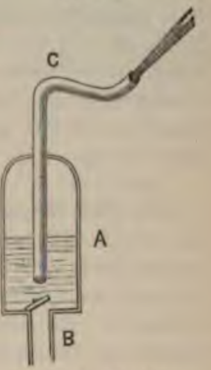
The bell-jar is represented at D. It is a cylinder of thick glass capable of resisting three or four atmospheres of pressure. The upper and lower edges of the cylinder are ground and fitted air-tight to plates of brass, E and F. Metallic rods, as shown at E and F, pass from one plate to the other. By the aid of the screw threads and nuts in which these terminate, the metallic plates are held firmly in position.

There are many applications of compression which are of interest. Among these is the air-gun. In this apparatus air is compressed in a reservoir, from which it is allowed to escape suddenly into a gun-barrel charged with a bullet. The propelling force of some of these instruments almost rivals that of gunpowder. They make less report than firearms, and as there is no smoke or flash, their use is not as easily detected as that of an ordinary gun or pistol.

Another application of the elastic force of compressed air is in the construction of the condensing chambers of force pumps, fire-engines, and hydraulic rams. The condensing chamber operates to convert the intermittent action of the pump into a continuous one. It consists of a stout metallic chamber, A.

Through the top of this a metallic tube passes nearly to the bottom. By means of a tube, B, which opens into the bottom, water is admitted at each stroke of the pump. The return of the water from the chamber is prevented by a valve which is placed at the opening of this tube. Between the lower end of the tube C and the top of the chamber A, atmospheric air is entrapped. At each stroke of the pump this air shrinks in volume, receiving the blow delivered by the piston. While the piston is making its return stroke, the compressed air exerts its elastic force and keeps a continuous stream flowing from the upper or open termination of the tube C.

FIG. 60.



Condensing chamber.

173. Life and Condensed Air.—In the air-bell of the compression pump we may study the effects of condensed air or other gas upon the respiratory function of small animals. The extensive use of the *diving-bell* and *caisson* in certain engineering operations, as the construction of the piers of bridges at great depths under water, the recovery of treasure or a valuable cargo from sunken ships, render the study of this subject a matter of importance. In certain diseases also the respiration of condensed air has proved to be a valuable remedial agent.

Water-tight diving dresses are now substituted for the diving-bell. They possess the advantage of giving the diver greater mobility, and his movements may be extended over considerable areas. Great care must be taken, both in the case of the diving-bell and the diver's dress, that no accident occurs to the tube by which air is supplied. A delay of two minutes in raising a man to the surface of the water, where accidents have occurred, has been attended by a fatal result.

Successful attempts have been recently made to avoid the operation of pumping air to the diver. On making a descent he carries a cylinder of compressed oxygen with him; from this a supply of fresh gas is conveyed to the interior of the dress, which holds sufficient atmospheric air to dilute the oxygen. Means for absorbing the carbonic acid are also supplied. In this way a diver has been enabled to remain for a much longer time under water, and move over very considerable distances.

It is said that the greatest depth to which one may descend in water is 160 feet. Under these circumstances the diver carries 100 pounds on his back and breast, and 25 pounds attached to the soles of his shoes. Though respiration under these condi-

tions is difficult, yet men have remained at this depth for 30 or 40 minutes. In one instance an experienced diver remained at a depth of 30 fathoms for 75 minutes, but he died within nine hours from congestion of the lungs.

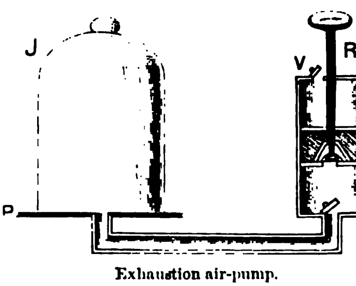
The power of the muscles of the chest to compress the air in the lungs is quite limited. Very few persons can blow air through a tube, the extremity of which is two feet perpendicularly under water. This, as we shall see hereafter, is only equal to a pressure of one pound to the square inch. By using the muscles of the mouth alone, a greater degree of compression may be exerted.

174. The Exhaustion Air-pump depends upon the elastic force of the air for its action.

Its parts are similar to those of the ordinary lift or suction-pump already described when treating of hydraulics.

Let P represent a ground-glass plate some ten inches in diameter, on this a bell-jar, J, is placed. The mouth of the jar

FIG. 61.



Exhaustion air-pump.

is also ground fine, so that with the plate it makes an air-tight joint. From the centre of the plate a brass tube passes to the bottom of the cylinder C. The cylinder must be accurately formed. The piston, of which R is the rod, should fit the cylinder perfectly air-tight. At the bottom of the cylinder at C, there is a valve, and also one in the piston B; both of these open upwards.

By means of the handle R the piston is thrown into action. At each stroke air is removed from the jar by its own elastic force, which is brought into play the moment the pressure is reduced at any point in the jar.

After a few strokes the force required to move the piston is very considerable. To relieve this, a valve, V, opening upwards is placed on the top of the cylinder; as each stroke of the piston is completed, this supporting the pressure of the air reduces greatly the amount of force required to work the pump.

In double cylinder air-pumps the pressure on one piston balances that on the other, and these valves are not needed.

There are many modifications of the form we have described. In all, the gradual removal of the air from the jar by repeated strokes of the piston finally produces a more or less perfect emptiness in the jar. To this the term *vacuum* is applied.

175. Life and Rarefied Air.—When a lighted candle is placed under the bell-jar of an air-pump, and exhaustion is made, it soon burns with a flickering light, and after a little the flame dies out. In like manner small animals, under the same circumstances, suffer distress long before a vacuum is reached.

Data have been obtained in the ascent of high mountains, which show that large animals as well as small suffer when the air is rarefied. At an elevation of 15,000 feet, where the air has about half the density it possesses at the level of the sea, respiration in men becomes more or less labored and difficult. At 16,000 feet of elevation, the hardiest mountaineers cannot walk ten yards without taking a rest, muscular action becoming almost impossible. In the vicinity of Quito it is found to be very difficult to make pack mules and horses advance above an altitude of 15,000 feet. They halt, tremble, and fall down. If rest is not allowed, they soon die. Travellers and even experienced guides frequently faint suddenly in the attempt to ascend lofty peaks. A mountain range over 15,000 feet in height is an effectual barrier between two nations. At double this height it is doubtful if any form of life exists, partly on account of the tenuity of the air and partly on account of the intense cold.

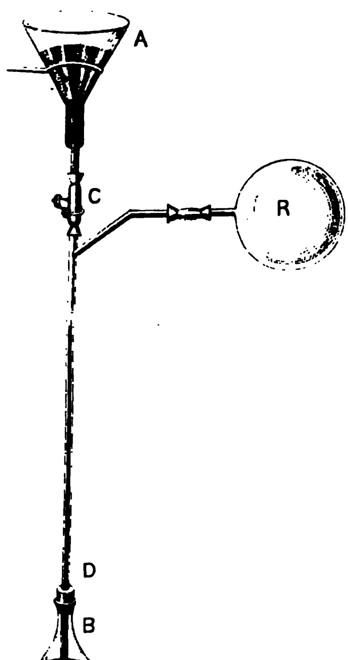
The exhaustion action of the walls of the chest, like their compression action, is limited to about one pound to the square inch. By the muscles of the mouth alone some persons can exert a wonderful exhaustion action, raising water nearly 30 feet, while others cannot raise it higher than 5 or 6 feet even in a narrow glass tube.

Though the forced respiratory act is limited to a pressure of one pound to the square inch, it is quite sufficient to draw various objects into the lungs. In persons who have been drowned, mud, sand, weeds, and other substances which have come into the vicinity of the mouth and nostrils are thus introduced into the lungs. Occasionally children are suffocated by having some object in the mouth at the time of taking a sudden violent inspiration. In this way marbles, thimbles, and pieces of candy have found their way into the bronchial tubes. Cases are also on record, in which comparatively heavy bodies like pins and needles have thus been carried into the air passages.

176. The Mercury Pump is also known as Sprengel's air-pump. In this a column of mercury is used to produce a vacuum. The

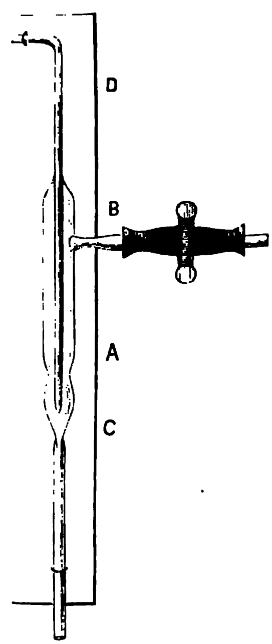
principle adopted consists in converting the space to be exhausted into a Torricellian vacuum (198). A simple form of this may be described as follows. In Fig. 62, C D is a glass tube about three feet in length and open at both ends. It is connected above by rubber tubing with a funnel, A, containing mercury, and properly supported. By a clamp on the rubber tube below C, the rate of flow of mercury into the vertical tube may be regulated. Just below the rubber tube a branch communicates with the flask R. The tube C D passes below into another flask B. In the side of this there is a spout. The end of the vertical tube passes below the level of this spout, and dips beneath the surface of the mercury contained in the flask.

FIG. 62.



Mercury pump.

FIG. 63.



Bunsen's filter pump.

On opening the clamp at C, the mercury runs down, and exhaustion begins, the air passing from the flask R forms alternate columns of air and mercury in the tube C D. As fast as the mercury flows from B through the spout into H, it is returned to the funnel A. As the exhaustion becomes more and more

complete, the columns of air in the vertical tube become shorter and shorter, until at last they disappear, and the tube seems to be filled with a continuous column of mercury throughout its whole extent. As this point is approached a clicking noise is emitted by the tube similar to that produced in the water hammer. Mercurial pumps of this description have been used for the preparation of Geissler tubes. To save time the first portions of air may be removed from the apparatus to be exhausted by means of an ordinary air-pump.

177. Bunsen's Filter Pump.—The process of filtration may be greatly aided by submitting the contents of the filter to the pressure of the air. Since it often happens that substances evolving fumes which would corrode the metallic parts of a pump are to be submitted to this operation, the apparatus represented in Fig. 63 was devised by Bunsen to accomplish this result.

It is essentially a Sprengel pump, in which a long column of water is substituted for the mercury. It consists of a glass tube of the shape shown at B A C. Water enters at B, and falling through A, passes down C, which is the top of a leaden or iron tube 35 or 40 feet in vertical height. As the water passes the narrow opening of the smaller tube D, it draws in the air from any apparatus with which that tube may be connected, and produces a vacuum therein.

178. Limit of Vacuum.—Theoretically an absolute vacuum cannot be obtained by the ordinary air-pump, since no matter how many strokes the piston may make it only removes a part of the air remaining in the jar. Even an infinite number of strokes would still leave some air in the jar. Practically the production of the vacuum is soon brought to an end for the following reason.

At each stroke of the piston and removal of air from the jar, the elastic force of the remaining air becomes less and less. Finally, it is reduced so low that it is not sufficient to raise the valves of the apparatus. All further exhaustion then ceases.

To overcome this difficulty air-pumps have been constructed in which the valves are worked by hand or by the movements of the piston, without calling the elastic force of the air into play. Examples of these are offered by the pumps of Babinet, Bianci, and Deleuil. By the latter it is said an exhaustion equal to a millimetre of mercury may be attained.

179. Vacuum by Chemical Agents.—To obtain a still more perfect vacuum various chemical means are resorted to for the removal of the last remaining traces of gas, even in the

Torricellian vacuum of a mercury pump. In the method adopted by Dewar, a vacuum estimated at $\frac{1}{350}$th of a millimetre of mercury was obtained. This method consists in heating charcoal to redness in a vessel which had been exhausted by a mercury pump. Finkener accomplished a similar result by filling the vessel with oxygen, exhausting this with the mercury pump, and then heating to redness copper which had been previously placed in the vessel. By similar chemical means Crookes has obtained a vacuum which he estimated at $\frac{1}{13000}$th of a millimetre.

CHAPTER XIII.

THE ATMOSPHERE.

General properties—Composition of air—Height of the atmosphere—Atmosphere presses downwards—Air presses in all directions—Action of lift-pumps explained—The pipette—The cupping-glass—Introduction of air into the lungs—Gases and principle of Archimedes—Balloons—Recent balloon ascents—Balloon traffic—Resistance of air to moving body—Parachute—Rate of movement into a vacuum—Cannon reports and thunder.

180. General Properties.—The atmosphere is the gaseous ocean covering the whole surface of the globe. It attends the earth in its motion of rotation, and would not change its relations to objects attached to its surface were it not for local disturbances chiefly the results of changes in temperature. To overcome these disturbances and reëstablish an equilibrium, currents are produced which we call winds.

Upon the atmosphere all plants and animals depend for their existence. They can only bear a deprivation of its supply for a brief period of time. The higher animals, as mammals, usually die in a few moments when deprived of air.

In experiments made on dogs, it was found that they might be deprived of air for three minutes and fifty seconds, and yet recover when air was admitted to the lungs. If the access of air was cut off for four minutes and ten seconds, death was the result. In this case the turning point between life and death was limited to twenty seconds. As it is not probable that a man would survive under these circumstances longer than a dog, the time during which access of air may be prevented is limited to less than four minutes.

In cases of death which have occurred in diving-bells, the limit of time has fallen as low as two minutes. Invertebrate creatures, like mollusks, have been submitted to the action of the vacuum of an ordinary air-pump for many hours, and have not only survived, but have apparently come out from the ordeal unharmed.

Of the atmosphere and its phenomena generally, we have the following graphic account by Dr. Buist, of Bombay: "Its upper surface cannot be nearer to us than fifty, and can scarcely be more remote than five hundred miles. It surrounds us on all sides, yet we see it not; it presses on us with a load of fifteen pounds on every square inch of surface of our bodies, or from seventy to one hundred tons on us in all, yet we do not so much as feel its weight. Softer than the softest down—more impalpable than the finest gossamer—it leaves the cobweb undisturbed, and scarcely stirs the lightest flower that feeds on the dew it supplies; yet it bears the fleets of nations on its wings around the world, and crushes the most refractory substances with its weight. When in motion its force is sufficient to level the most stately forests and buildings with the earth, to raise the waters of the ocean into ridges like mountains, and dash the strongest ships to pieces like toys. It warms and cools by turns the earth and the living creatures that inhabit it. It draws up vapors from the sea and land, retains them dissolved in itself or suspended in cisterns of clouds, and throws them down again as rain or dew when they are required. It bends the rays of the sun from their path to give us the twilight of evening and of dawn; it disperses and refracts their various tints to beautify the approach and the retreat of the orb of day. But for the atmosphere, sunshine would burst on us and fail us at once, and at once remove us from midnight darkness to the blaze of noon. We should have no twilight to soften and beautify the landscape, no clouds to shade us from the scorching heat, but the bald earth as it revolved on its axis, would turn its tanned and weakened front to the full and unmitigated rays of the Lord of Light."

181. Composition of Air.—Air is a mixture of gases. The chief of these are oxygen and nitrogen. Next in importance are vapor of water and carbonic acid gas. Many other gases are present in minute proportions or traces. Excluding these, its composition may be expressed as follows:

Nitrogen	78.49
Oxygen	20.63
H_2O (vapor of water)	0.84
CO_2 (carbonic acid gas)	0.04
	100.00

Aqueous vapor arises by evaporation from the earth's surface and from collections of water, also from the exhalations of plants and animals. Carbonic acid gas is produced in the respiration of animals and in all processes of combustion, decomposition, putrefaction, and fermentation. It has been estimated that in Paris the diurnal production of this gas amounts to one hundred millions of cubic feet, of which one-tenth is from the respiration of human beings and animals, the remainder arising chiefly from processes of combustion. Accumulation of carbonic acid gas in the air is prevented by plants, which decompose it, and setting its oxygen free unite its carbon with water to form gum, with which they build up their tissue.

From the table given above, we find that a certain small proportion of carbon dioxide is always present in the air. When air is expired from the lungs, it has lost from four to six per cent. of oxygen, and has gained in its stead from three to five per cent. of carbonic acid gas. The presence of six to ten per cent. of this gas in air is fatal to life. In an atmosphere containing this proportion of carbonic anhydride a candle will burn. It is, therefore, evident that the candle test does not necessarily show that it is safe to descend into a pit or well where it will burn. It only indicates that descent is absolutely negatived where it does not burn.

Although oxygen is necessary for the maintenance of life, it must be used in the diluted condition in which we find it in air. When breathed in the unmixed state, it stimulates the nervous system strongly and finally causes death. The experiments of Mr. Broughton showed that rabbits died in from six to twelve hours when kept in pure oxygen. Despite the noxious action of pure oxygen, animals will live in an atmosphere of that gas three times as long as they will live in an equal volume of atmospheric air.

182. Height of the Atmosphere.—The facts which have been presented regarding the elastic force of air in common with all gases would lead us to expect that its molecules would fly off into space. That this is not the case is apparent from the fact that it does remain bound, as it were, to the surface of the earth.

This apparent contradiction receives its explanation in the fact that as air expands its elastic force becomes less. Moreover, as it ascends to higher regions the cold is more intense, this also diminishes the tendency to expansion, until finally it is reduced to so low a point that it comes under the control of gravity, and an equilibrium being established expansion ceases, and an exterior limit or boundary between the atmosphere and space is established.

Observations on the density of air and of phenomena of

refraction connected with twilight, show that the depth of the atmospheric ocean is probably from forty to sixty miles. The great mass of the air by weight is, of course, confined within a small fraction of that depth. In opposition to this estimate the objection is raised that meteorites are often seen to emit light when they are still more than 200 miles above the earth's surface. Since the luminosity, in this case, is the sequent of the action of the air, it follows that we must extend the outer limit to that distance. Recent observations on the twilight arc by Mr. Liais, at Rio Janeiro, also tend to place the outer limit of the atmosphere at a distance of about 200 miles.

183. The Atmosphere Presses Downwards.—Turning to the description of the air-pump (174), and repeating the experiment therein detailed, it will be found that after a few strokes of the pump it becomes almost impossible to separate the bell-jar from its plate. This is explained upon the following principles. It has been shown that air is heavy, 100 cubic inches weighing 31 grains. In the last article, we have also seen that the depth of the aërial ocean is variously estimated at from forty to two hundred miles. Though it is true that the atmosphere by its expansion gradually becomes lighter as we leave the surface of the earth, yet a long distance must be traversed, nearly 4 miles, before the weight of 100 cubic inches has even diminished to one-half that which it had at the surface.

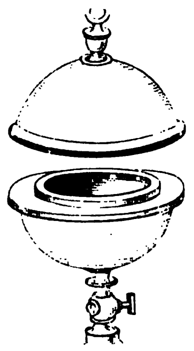
The air being heavy and there being so great a column of it resting on the top of the jar, we can easily understand that this is the reason why the jar is so firmly pressed down upon the plate of the pump. If any doubt exists regarding this explanation, it only remains to allow the air to regain access to the interior of the jar. As it passes in, its pressure is brought to bear on the interior as well as the exterior, and at last equilibrium is established between the interior and exterior pressures, and the jar may be removed from the plate of the pump with the same ease as before the experiment began.

A capital illustration of the downward pressure of air is offered by a toy, well known to boys as the *sucker*. It consists of a circular piece of thick leather, which is soaked with water. Through the centre a strong string passes, which is prevented from slipping through by knots made on the lower side. The leather having been well applied to the surface of a stone or other flat object, and traction applied by the string, the stone is raised; the pressure of the air binding the stone tightly to the leather.

184. Air Presses in all Directions.—The study of hydrostatics shows that water presses in all directions. The similarity which

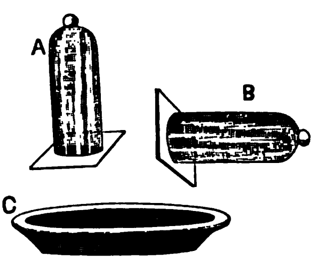
we have seen to exist between liquids and gases, regarding their properties, would lead us to expect that air would also press in all directions, and equally in the same plane as is the case with water. The experimental demonstration that such is the fact may be made in a number of ways. Of these the most classic is by the Magdeburg hemispheres represented in Fig. 64. The arrangement consists of two hollow hemispheres of brass, the edges of which are accurately ground. When placed together a hollow sphere is formed, access to the interior of which is offered by the stopcock. The hollow sphere being attached to the air-pump plate and exhausted, the stopcock is then closed, and the apparatus removed from the pump. No matter in what direction traction is now applied to separate the two hemispheres, they are pressed together with equal firmness in all. It is, therefore, evident that air exerts pressure equally in all directions.

FIG. 64.



Magdeburg hemispheres.

FIG. 65.



Air presses in all directions.

The same result may be obtained in a more inexpensive manner, by the device illustrated in Fig. 65. Let A be a small bell-jar, or a wine-glass. It is to be filled with water over the dish C. The mouth is then to be closed by a sheet of card-board, care being taken that no air is entrapped between the card and the surface of the fluid. Thus prepared, the jar may be turned mouth down. The water nevertheless remains suspended in the jar by the pressure of the air on the sheet of card closing its mouth. The glass may then be inclined at all angles, B, yet, so long as the card does not slip, the water is retained *in situ* by the pressure of the air.

Nature offers numerous illustrations of the application of the pressure of the air. The movements of flies, and other insects, along the smooth ceiling of a room, are accomplished on this

principle. The tree toad also depends upon pressure of the air on the suckers of his toes for his ability to move as easily on the under as on the upper side of a branch. It is the presence of numerous suckers on the under surface of the arms of cuttle-fishes, that gives that creature its fearful hold upon whatever it touches. The great joints of our bodies are also held together firmly by pressure of the air. The ligaments of many of them may be completely severed, yet it is as difficult to separate the bones from each other, as it would be to tear asunder two Magdeburg hemispheres of equal diameter.

By calling the pressure of air into play, the infant draws its supply of milk from its mother's breast, and, following the precepts of his infancy, adult man imbibes the consolation to be found in a sherry cobbler through the medium of a straw and by grace of the pressure of the air.

185. Action of a Lift-pump Explained.—The apparatus represented in Fig. 66 is known as the experiment of the fountain in vacuo. It consists of a tall jar, A, through the lower part of which a tube passes. This is furnished with a stopcock at B, and terminates in a jet in the interior of the jar. The exterior termination of the tube bears a screw thread by which it is to be attached to the air-pump. Exhausting the jar and closing the stopcock, the apparatus is detached from the pump, and introduced vertically into a basin, C, containing water. Passing the external extremity of the tube to the bottom of C, and opening the cock B, a fine stream of water rises from the jet and impinges forcibly against the top of the jar, where it turns and flowing down the sides accumulates at the base. The cause of the formation of this fountain is evidently the pressure of air upon the surface of the water in C. The moment the cock is opened this pressure is brought into action, and the whole train of phenomena initiated.

FIG. 66.

Fountain in vacuo.

As in the preceding case, the pressure of air forces the water up into the vacuous space A, so when by a downward stroke of the handle in a lift-pump we make a partial vacuum in the cylinder, the water, with which it is connected by the pipe, is forced up into the pipe by pressure of the air upon the surface of the fluid in a well or cistern.

186. Action of a Pipette.—For the transference of urinary sediments to a microscope slide, and also for the transference and measurement of small quantities of liquid, the apparatus known

as a pipette is very useful and convenient. It consists of a glass tube, A B, of the form shown in Fig. 67. The upper part, A, is open the full diameter, the lower, B, is drawn down to a fine point or jet, and dips into the bottle C. The fluid may then, by placing A in the mouth, be drawn into the pipette to a measured mark, the end closed by the finger, and the fluid transferred to another vessel.

FIG. 67.

Pipette.

Suppose *sediment* in the bottle C to be removed to the capsule D. The mouth, A, of the pipette is closed with the finger, the extremity, B, is then passed down into the sediment. As A is closed by the finger, the air in the pipette prevents the ingress of the fluid while the pipette is passed through it. The point of the pipette being advanced into the sediment, the pressure of the finger on the opening A is slightly relaxed, a little air escapes, and the pressure of the atmosphere on the surface of the liquid forces it and the sediment into the pipette. A sufficient quantity having passed into the pipette, the pressure of the finger at A is restored, and the instrument is removed from the bottle. As it passes into the air, the pressure of the atmosphere on the narrow column of fluid in the jet of the pipette retains the fluid and precipitate in position until it is held over the capsule D. The pressure of the finger at A being then released, the air gains access to the tube above, and a portion of liquid and precipitate is forced out.

The rate of flow from a pipette is regulated by inclining it more or less at an angle to the perpendicular. If it is held vertically, the flow is the most rapid. If held horizontally, it may be diminished to nothing. Between these all rates desired may be obtained.

187. The Cupping-glass.—The effect of the pressure of air on the tissues of the body may be shown by the apparatus known as the hand-glass. It consists of a glass vessel or receiver, of the shape represented at A, Fig. 68, open above and below. The lower mouth is five inches, and the upper two inches in diameter. The lower mouth, having its edges finely ground, makes an air-tight joint when placed upon the plate of the air-pump B. Closing the upper, or smaller opening, with the palm of the hand and exhausting, the pressure of the air is brought to bear upon its dorsal surface. As the exhaustion is continued, the muscular and other tissues are forced down between the

metacarpal bones, the outlines of which may be easily traced on the back of the hand. At the same time the palmar surface is bulged downwards into the receiver. It becomes intensely congested with blood, and if the exhaustion is sufficiently perfect, and continued for a sufficient time, the smaller bloodvessels are ruptured and ecchymosis produced.

FIG. 68.

Hand-glass and cupping-glass.

The cupping-glass acts on the same principle as the hand-glass. It is usually shaped like a low bell-jar C, and made either of metal or of glass. The rim around the opening should have sufficient thickness to prevent it cutting the skin when applied.

Sometimes cups are exhausted by means of a small air syringe. When this is the case they are perforated above, and the opening closed by a stopcock when the exhaustion is completed. Generally the vacuum is produced by the condensation of vapor of water. In this case the cups are without any perforation above. Ordinary tea or coffee cups with thick lips answer perfectly well. The method of application is as follows. A small torch is prepared by wrapping a few folds of old linen around a penhandle. This is dipped into alcohol, and lighted. A copious flame is thereby produced. The mouth of the cup is then held close to the surface to which it is to be applied, the torch is passed into the cup, and almost immediately withdrawn. At the moment of withdrawal, the mouth of the cup is turned down on the surface of the skin. If it does not adhere at once, the torch is again applied.

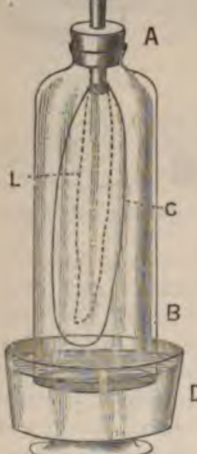
The operation of the flame is to fill the cup with steam of high tension. The air is thus expelled, and if the mouth of the cup is closed by the skin before the steam begins to condense, when it does condense a vacuum is produced in the cup. The application of the flame to the interior should be momentary, otherwise the cup will be heated, condensation of the steam will be imperfect, and the surface to which it is applied may be scorched. It is well to moisten or bathe the surface of the skin before the application of the cups is commenced. It is thus softened, and better opportunity offered for forming an air-tight joint.

When a wound is accompanied by injection of poison, as in the *bite of a venomous serpent*, a cupping-glass may be used to withdraw the noxious matter from the part. Since, under these conditions, rapidity of removal of the poison is all important,

the mouth may be at once applied, and the wound sucked until cups can be procured. The person who offers his services in such a case should be certain that there is no wound or abrasion of the skin about his lips or buccal cavity. If there is he may lose his life in consequence, for though such poison may be swallowed with impunity, it destroys life if brought in contact with a raw surface or wound.

188. Introduction of Air into the Lungs.—In all the mammalia or higher animals, pressure of the atmosphere is brought into action in the introduction of air into the larger air-passages. By means of the apparatus shown in Fig. 69 we may illustrate the manner in which the first stage of inspiration and the last of expiration are accomplished.

Fig. 69.



Inspiration and expiration of air.

Let A B be a bell-jar perforated above, and dipping into a vessel of water, D. The walls of the jar may be imagined to represent the walls of the chest. The surface of the water in D would represent the diaphragm, and by raising and lowering D in a regular rhythmic manner, the action of the diaphragm may be imitated, and the capacity of the interior of the jar A B increased and diminished. The aperture at A is to be closed by a cork, through which an open tube T passes, and terminates in the interior of the jar in a rubber sack, or a bladder, shown at C. Carrying out the substitution of parts, the tube T represents the trachea, and the sack C the lung. The dotted line shows the form of the bag when D is raised, and the capacity of the chest or bell diminished. Lowering D, the capacity of A B is increased, the air flows in through T to L, exactly as when the diaphragm is lowered it flows through the trachea into the lungs, and the inspiratory act is accomplished. Raising D, the capacity of A B is diminished, pressure is brought to bear on the bladder C, it contracts, its contents passing out through T. In like manner the expiratory act is accomplished. The diaphragm being pressed up by the contraction of the abdominal muscles, it bulges upwards, the capacity of the thoracic cavity is diminished, the lung yields to the pressure, and the foul air is expelled through the trachea.

In these movements the total amount of compression and rarefaction of the air is quite small, not amounting to more than half an inch of water each way. This may be proved by

breathing with the nostrils unobstructed, and with a tube one end of which is placed in the mouth while the other end is kept an inch or so under water.

The average total *capacity of the lungs* in the adult male is 335 cubic inches. The average amount of air introduced at each inspiration is 30 cubic inches, and there are about 18 respirations per minute. This gives 540 cubic inches per minute as the amount of air inspired and expired by these organs.

189. Gases and Principle of Archimedes.—The experiment with the Magdeburg hemispheres demonstrated that air presses equally in all directions upon bodies placed therein, acting in this respect in the same manner as water. It is, therefore, evident that the laws regarding the equilibrium of bodies in liquids are applicable to bodies in air, and *they must lose a portion of their weight equal to that of the air they displace.*

That this really happens is demonstrated by the instrument called the *baroscope*, which is represented in Fig. 70. It consists

Fig. 70.

Baroscope.

of an arm or lever A B, moving on the fulcrum F. To the extremity A, a sealed glass globe is attached which is filled with air. To the opposite extremity a counterpoise of lead, B, is suspended. The two objects A and B are so adjusted that in the air they balance each other when the lever A B is horizontal.

Placing the arrangement under a large bell upon the air-pump plate, after a few movements of the piston, the globe A descends, showing that it is really the heavier of the two bodies. The only rational explanation that can be given of this is, that before the air was removed from the jar it buoyed up each body just as water would do. On removing the air, since the sphere was the larger mass, it suffered most from the loss of buoyant power of

the air, and that end of the lever consequently sank because it was the heavier.

That the loss of weight in the globe, while in the air, is actually owing to the bulk of air it displaces, is readily shown by measuring the capacity of the globe, and adding the corresponding weight to the counterpoise. Suppose the globe measures 100 cubic inches, adding 31 grains, which is the weight of this volume of air, to the leaden counterpoise, that side will be heavier in the air, but in the completely exhausted receiver of the air-pump it will exactly balance the globe, thus proving the point in question.

In place of a globe containing air and its counterpoise, an ounce of cork may be attached to one arm, and an ounce of lead to the other arm of the baroscope. In the air-pump vacuum the cork will be the heavier. The indications of the baroscope show us the necessity, in exact scientific work, of either weighing bodies in vacuo, or of giving their weight reduced to what it would be in vacuo.

190. Balloons depend upon the buoyant power of the air for their action. They are immense bags made of some light material, as silk, covered with a caoutchouc varnish. This is enclosed in a network of cord, from which a car of wickerwork is suspended. In the top of the balloon there is a valve to permit the escape of gas; this is managed by a cord which passes down to the car.

The car carries a certain number of bags of sand; by means of these and the valve the balloon may be made to rise and fall at the will of the aëronaut. If he desires to pass to a lower stratum and avail himself of the direction of the wind of that region, he opens the valve and allows sufficient gas to escape to accomplish this purpose. The rise or fall is produced by a variation of a very few pounds in the weight of the machine. If he desires to ascend, he allows a portion of the sand ballast to escape. Thus the balloonist can pass to one or another stratum of air, and so obtain a certain amount of control over the course of his aërial car.

A balloon 35 feet in diameter will hold about 22,000 cubic feet. The weight of this bulk of air is 1600 pounds, of hydrogen 200 pounds, and of coal-gas about 640 pounds. Filled with hydrogen it would have a carrying capacity for material, car fixtures and load of 1400 pounds. Filled with coal-gas its carrying capacity would be less than 1000 pounds. Though the ascensional power of hydrogen is so much greater than that of coal-gas, the latter is used in preference, since it is much cheaper and has less tendency to leak or to pass through the material of which the balloon is made. The largest balloon that has been

constructed was nearly 100 feet in diameter, it had a capacity of 450,000 cubic feet; charged with hydrogen, it ascended with thirty-two persons to a height of 2000 feet.

The first balloons were raised by means of air rarefied by heat. From their discoverer they were called Montgolfiers. The first ascent was made by one of these in June, 1783. Shortly after this, in December, 1783, hydrogen was used as being less dangerous. In 1814, when coal-gas was introduced for lighting cities, it was substituted for hydrogen in balloons.

An ascent made by Gay-Lussac in 1804 is worthy of mention on account of the scientific, and especially the physiological

Fig. 71.

Balloon.

information obtained. The height reached was 23,000 feet; the barometer sank to 12.6 inches; the thermometer, 31° C. at the ground, sank to —9° C. The air was so dry that paper shrank and crumpled as if it had been held near a hot fire. Respiration was greatly accelerated, and the pulsations of the heart, which were normally 66, became 120. Such profound disturbances of the functions of the body lead us to wonder that no attempt has been made to utilize *balloons as a remedial agent in the treatment of certain diseases.* Certainly it would seem that captive balloons might be employed in great cities for

the purpose of raising patients suffering with various complaints to a sufficient height to give them a supply of pure air during a few hours of the day.

191. Recent Balloon Ascents.—In September, 1861, Glaisher made an ascent of which the following is the record. Left the earth at 1 P.M., in 23 minutes reached an altitude of 15,750 feet; in 11 minutes after 21,000 feet, temperature —10° C. At 1.52, the altitude was 29,000 feet; temperature —16° C. The observer then fainted. The lowest proximate estimate of barometric height was 7 inches. This would correspond to an elevation of 36,000 feet.

At 19,000 feet Glaisher had no difficulty in making observations, though his companion panted for breath. At 29,000 feet his eyesight failed; the sense of hearing and other faculties remained a little longer. Muscular power was entirely lost, and his companion was partly paralyzed by the intense cold.

An ascent made by the balloon "Zenith," in April, 1875, resulted fatally to two of the occupants, the third barely escaping with his life. The object of the ascent was to determine the amount of carbonic anhydride and vapor of water at great elevations. The aëronauts were Tissandier, Sivel, and Croce-Spinelli.

The rate of ascent was nine feet per second at the start, this slowly diminished. In 90 minutes an altitude of nearly 23,000 feet was reached. The travellers had a supply of oxygen with them, by which they were enabled to maintain respiration. At this point some ballast was thrown out. The ascent became more rapid, and Tissandier fainted. The balloon then descended. On recovering, all being well, more ballast was thrown over, and, at the same time, Spinelli threw overboard the aspirator, weighing 80 pounds. In the sudden rise that followed Tissandier became unconscious, and remained so for an hour. When he regained his senses, he found the balloon rapidly descending, and very little ballast left. The other occupants of the car were both dead, their faces black and covered with blood which had escaped from the mouth and nose.

The maximum height recorded by the instruments was over 28,000 feet. It is probable that death was caused by suffocation, the result of the second rapid transition to a very rarefied atmosphere which followed the casting out of the aspirator.

On many previous occasions life had been lost on the earth's surface. The deaths of Sivel and Croce-Spinelli were the first recorded in the uppermost regions of the air, and great were the honors paid by France to her martyrs in the cause of science.

192. Balloon Traffic.—During the investment of Paris by the Prussians, in 1870, a regular balloon service was established.

These balloons were spherical, and contained about 70,000 feet of gas. They were started in the evening. In the four months, beginning with September 23, sixty-four left Paris, laden with 161 passengers, and nine tons of despatches, containing about 3,000,000 letters. Out of the total number, 57 reached their destination, 2 were lost at sea, and 5 were captured by the Prussians. By this means Jansen, the astronomer and physicist, escaped from the beleagured city, and taking his instruments with him made observations in the south of France on an eclipse of the sun.

193. Resistance of Air to Moving Body.—In (132) the resistance of water to the movement of bodies therein was discussed, and experimentally illustrated. In the same manner, though to a less extent, air resists the passage of objects. This is shown by the instrument known as the guinea and feather tube, Fig. 72. It consists of a stout glass tube, three inches in diameter, four or five feet long, and hermetically sealed below. The upper part is closed air-tight by a brass cap, through which a brass tube provided with a stopcock passes. In the interior of the glass tube, a disk of brass and a disk of paper of equal size are placed.

Fig. 72.

Resistance of air to moving body.

When the apparatus is filled with air, and quickly inverted, the metal drops immediately from one end of the tube to the other, while the paper slowly sinks, requiring at least ten times the time occupied by the metal to pass through the length of the tube. Attaching the tube to the air-pump, exhausting it, closing the stopcock A, removing the apparatus from the air-pump plate, and again quickly inverting it, the paper and the metal fall together from one end of the instrument to the other. If the vacuum is good, there is no perceptible difference in their velocity. The paper moves as rapidly as though it were a mass of lead. Opening the stopcock, and admitting air, the paper comports itself in the normal manner, and sinks slowly. The natural explanation of the phenomena in question, is that air resists the passage of objects, acting in this respect in the same manner as a fluid.

When the rate of movement is rapid, as in the case of a railroad train, the resistance of the air is then very evident, the hand readily perceiving it, and if the head be passed outside of

the car window, with the face turned in the direction of the motion, serious interference with the act of respiration is experienced. It is this resistance of air that chiefly puts a practical limit to the rapidity of movement of railway trains. It also quickly reduces the velocity of the rifle-bullet, and, in order to avoid it, the lightning flash is driven to a zigzag course.

194. Parachute.—In the use of balloons accidents have at times occurred, either from the valve becoming fixed or from rents in the balloon. Under these circumstances the aëronaut is enabled to leave the machine by the apparatus in question. A parachute may be described as an immense umbrella some 16 feet in diameter, and capable of being folded up in the same manner. In the top there is a small opening. Leaving the balloon the parachute expands, and descends slowly on account of the resistance of the air to the great area of surface it offers. The air being compressed in the hollow of the apparatus escapes through an opening in the top, thus the descent is regulated, and freed from the swaying motion it would otherwise have.

Fig. 73.

The parachute.

195. Rate of Movement into a Vacuum.—The resistance of air to moving bodies shows that though very mobile its particles have a certain amount of viscosity, and require time for the execution of movements. It, therefore, follows, that as time is required by the molecules of air to get out of the way of a rapidly moving body, time must also be required for them to fill in the space behind an object in rapid motion. When the velocity of the body is very great, as when a cannon-ball first leaves the mouth of a gun, there is an almost perfect vacuum for a certain distance behind the shot. The question arises, What is the rate at which air can flow into this vacuum? Many attempts have been made, and various methods adopted, for the solution of this problem. That which appears to offer the greatest probability of accuracy, places it at about 1280 feet per second, which is more rapid than the rate at which sound traverses the atmosphere under ordinary conditions.

196. The Cannon Report and Thunder.—In explanation of these phenomena, the following experiments are offered. At A B,

Fig. 74, the instrument known as the *water hammer* is represented. It is made of glass, stout enough to resist the pressure of the air when a vacuum is made in its interior. The tubular portion B is somewhat more than half filled with water. The space above this is vacuous or contains vapor of water, no air. Holding the instrument in the position represented, and giving it a rapid upward movement, which is suddenly changed to a downward one, the column of water either leaves the bottom of the tube or breaks into two portions. The upper mass, drawn down by gravity, falls on the bottom or lower portion, and striking it emits a clicking sound. To produce this result the vacuum must be very good, since the presence of even a small portion of air, by its elasticity, takes off the shock and prevents emission of sound. From this we learn that two fluids or a fluid and a solid striking against each other in a vacuum produce sound vibrations which pass from the fluid through the glass to the air, and so affect our sense of hearing.

Fig. 74.

Water hammer.

In the experiment, Fig. 75, A B represents a glass, the upper mouth of which, A, has been closed air-tight by a portion of bladder or some membranous structure. Placing the instrument with its other mouth, B, on the plate of an air-pump, and proceeding to exhaust, the pressure of the atmosphere borne by the membrane at last becomes so great that it suddenly ruptures, and the column of air falling on the plate of the air-pump produces a sound almost equal to that of a pistol-shot. In this case, the noise has originated in the sudden impact of a gas on a solid, there being comparatively little air intervening to interpose its elasticity.

Fig. 75.

Burst bladder.

With these illustrations before us we can understand the origin of the sound emitted by a rifle-shot in its passage. Its velocity approaching a couple of thousand feet per second as it leaves the gun, a vacuum is of necessity formed behind it. Into this cylindrical track of vacuum the air rushes at the rate of over 1200 feet per second from all sides. The opposing columns meeting at the axis of the cylinder produce sound, just as it is produced in the water hammer when the two columns of water strike together in the vacuum.

In the track of the lightning flash a vacuum is also produced. The reverberations of thunder which accompany lightning in its course are the clashing together of the walls of the vacuous track the lightning has cleaved through the atmosphere. Verily no better evidence of the materiality of air can be offered than the fearful crash which attends the striking of lightning near by.

CHAPTER XIV.

BAROMETRY.

Galileo's explanation—Torricelli's experiment—Pascal's experiment—Pressure of the atmosphere—Cistern barometer—Fortin's barometer—Siphon barometer—Wheel barometer—Glycerine barometer—Errors in barometric reading—Barometric variations—Mean barometric heights—Cause of barometric variations—Barometric variations and the weather—Barometer and the winds—Barometer and the death rate.

197. Galileo's Explanation.—The explanation of the principle upon which the barometer depends, is best attained by a brief review of the history of its discovery. About the year 1642, an attempt was made at Florence, in Italy, to raise water by means of a lift-pump to the upper stories of a palace which had been recently erected. Galileo, the leading philosopher of the day, was called in consultation by the Grand Duke, and after many experiments found that no matter how perfect the construction of the pump, water could not be raised thereby to a height greater than about thirty-four feet.

In those days the cause of the rise of water in a pump was attributed to "Nature's horror of a vacuum." This explanation had passed unchallenged for many centuries. Galileo gave it as his opinion, that the reason why a pump could not raise water higher than thirty-four feet was because that was the limit to which the pressure of air could force it, an explanation which had been suspected as far back as the days of Aristotle.

198. Torricelli's Experiment.—Torricelli, a pupil of Galileo's, sought to prove his master's explanation. He suggested that since air had been shown to have weight, the true reason why the water rose in the pump was because the air pressed on the surface of the water in the cistern, and so forced it up.

The reason, he added, why there was a limit to the height was, because when the air had forced up a column of fluid equal to its own weight, equilibrium was established, and no further rise was possible.

In demonstration of this theory he proposed the following experiment. Substituting mercury for water, he argued that since it was thirteen and a half times as heavy as water, and a pump could raise water about 34 feet, therefore it should raise mercury about 30 inches. Finding that such was the case, he contrived the instrument we now know as the barometer, or measurer of the weight of air.

For the *construction of the barometer*, a tube, A, of stout glass is required. It should have a bore about one-quarter of an inch in diameter, and be thirty-four inches in length. One extremity, A, should be hermetically sealed, and the other open. It should be chemically clean in the interior. It must be filled with pure mercury, and every bubble or trace of air carefully removed. This may be done in the following manner, when the object is to offer a lecture-room illustration of the construction of the instrument. The tube is filled to within half an inch of the open end, it is then closed by the finger, and inclined so that the large entrapped bubble of air passes to the other end. In its course it licks up all the small bubbles that have been caught between the mercury and the wall of the tube. The removal of the air may be facilitated by heating the tube; the bubbles of air are thus expanded. The tube finally assumes the appearance of a rod of polished steel. For the method of filling the barometer for accurate scientific research, see (3d, 206).

FIG. 76.

Barometer.

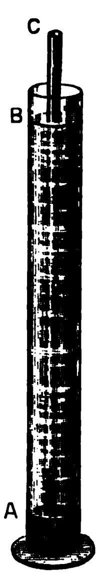
All air having been removed, the tube is filled with mercury. Its open extremity is closed by the finger, and it is placed with its mouth downwards under the surface of mercury in a small basin or cistern, B. Removing the finger from the mouth of the tube, the mercury drops from the upper or sealed extremity, and after a few oscillations stands at a vertical height of about thirty inches above the level of that in the basin. The empty space between the top of the mercury and the top of the tube is called the *Torricellian vacuum*. It was for long supposed to be a perfect vacuum, but is now

known to contain traces of vapor of mercury, together with moisture, and the last portions of air which cannot be removed.

Any movement of a barometer thus constructed is attended by oscillations of the liquid in the tube. It often strikes the sealed end with such force as to cause fracture of the glass. To avoid this the tube should be held in an inclined position, the mercury then rises to the top and there remains. There is then no oscillation and liability to fracture is avoided.

The manner of action of air in forcing mercury up the barometer tube, may be illustrated by the following experiment. Let A B represent a jar three feet in height and four inches in diameter. Sufficient mercury is poured into it to make a layer half an inch deep at the bottom. Into this a tube, C, longer than the jar, and with both ends open, dips. The mercury is seen to stand at about the same level in the tube and in the jar. Let water be poured into the jar. It presses upon the surface of the mercury at A; as more water is added the mercury rises higher in the tube. In like manner, pressure of the air upon the surface of the mercury in the cistern of a barometer forces that liquid up its tube.

FIG. 77.



Action of barometer illustrated.

199. Pascal's Experiment.—Torricelli did not long survive his discovery. Shortly after his death, Pascal took the subject up, and completed the demonstration by two methods of procedure.

1st. He argued that if Torricelli's explanation is correct, and the mercury is suspended in the barometer tube by the pressure of air, it follows, that if the instrument is carried up a mountain, and the column of pressing air reduced in altitude, the mercury must fall in the tube, and stand at a much lower level. Under his direction the experiment was tried on the summit of the Puy de Dôme, in Auvergne, when it was found that the level of the mercury was three inches lower than it was at the base of the mountain.

Pascal's experiment may be illustrated by placing a barometer under a tall air-pump jar. On exhausting the jar, and so reducing the pressure upon the mercury in the cistern, the same effect is produced as though the instrument was carried up a mountain, and the liquid falls in the tube. By pushing exhaustion to the extreme, the mercury in the tube

and that in the cistern may be made to occupy very nearly the same level. Restoring the pressure of air, the mercury again rises in the tube, and with restoration of the original pressure it regains its normal height of thirty inches above the level of that in the cistern.

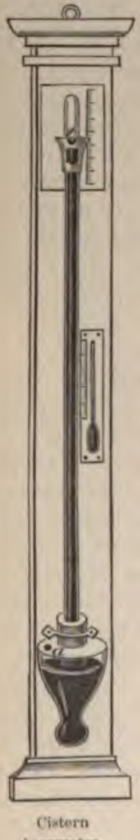
The second method of Pascal was to repeat Torricelli's experiment with a variety of liquids. Using a tube fifty feet in length, and manipulating with it as a barometer, he found that when it was filled with water that liquid stood at an altitude of thirty-four feet, or thirteen and a half times as high as the column of mercury. Mercury being thirteen and a half times as heavy as water, it followed that the weight of the column of water was exactly equal to the weight of the column of mercury used in Torricelli's experiment. Consequently the columns were in each case supported by the same force, and that could be none other than the pressure of the air. Experiments with wine and oil gave like results.

200. Pressure of the Atmosphere.—If we grant that the tube used in the construction of a mercurial barometer has a transverse area equal to one square inch, and the mercury stands at an altitude of thirty inches, it follows that the column is equal to thirty cubic inches of mercury. The weight of this mass of mercury is nearly fifteen pounds. Consequently since this balances a column of air of equal area, it is evident that *the pressure of the atmosphere on a square inch of surface is equal to fifteen pounds.* This is about one ton to the square foot. As the surface of an ordinary human body is about sixteen square feet, it follows that the pressure thereon must be equal to sixteen tons. The only reason we are not crushed to earth by this fearful incubus of weight is, that it acts on the interior as well as the exterior of the body, and so the exterior pressure is counterbalanced or neutralized. That this is really the case is shown by the fact that when pressure on any part of the surface is removed, as in the act of cupping, that portion is immediately forced outwards.

When any gas, vapor, or fluid, bears upon a surface in such a manner as to exert a pressure of fifteen pounds on each square inch of the surface, it is said to exert a *pressure of one atmosphere;* that being, as we have seen, the weight with which the atmosphere presses. If, for example, steam in a boiler is exerting a pressure of sixty pounds on every square inch, we say that the elastic force of the steam is equal to four atmospheres of pressure. According to the metric system atmospheric pressure at 0° C. and the level of the sea, is equal to a column of mercury 760 millimetres in height, and the pressure on a square centimetre is 1.03296 kilogramme.

201. The Cistern Barometer.—Various forms have been given to the barometer. That usually employed, and the simplest in construction, is the cistern barometer, Fig. 78. It consists of a Torricellian tube about thirty-four inches in length, which is firmly attached to an upright support. This is constructed that it may be hung by the top and a perpendicular position secured.

FIG. 78.



Cistern barometer.

In measuring the height of the column of mercury in the barometric tube, the point of departure for the measurement is the surface of the mercury in the lower cup or cistern. From this to the top of the mercury in the tube is the height of the column balancing the air pressure at the time of observation. It is, of course, understood that this measure is taken with the tube in a perpendicular or vertical position.

As the mercury in the barometer rises and falls in the tube, more or less of it passes into the cistern. The quantity in the cistern being, therefore, variable, the zero of the scale of measurement is variable. To avoid this error, the cistern is made as wide as possible in its upper part that the variations in level may be reduced to as small a fraction of an inch as possible. It is this enlargement of the cistern that gives the name to this form of instrument. The cistern is not entirely closed in from the air, an opening is left in the top, in the position shown at *a*. Through this air has access to the surface of the mercury, and variations in its pressure are not interfered with.

Comparing the altitude of the column of mercury with that of the air which it is balancing, the length of the former is exceedingly small compared with the latter. It is, therefore, necessary to read the barometric variations to very small fractions of an inch. Even in ordinary barometers the readings are to hundredths of an inch. To read minute quantities such as this with even an approach to accuracy, the device known as a *vernier* is employed.

202. Fortin's Barometer.—In this the error of cistern level in the preceding form is eliminated, and the instrument is at the same time made more portable. The main difference is in the construction of the cistern. This is composed of a glass cylinder, A, the bottom of which is formed by a piece of leather, B.

iinst the centre of this a wooden button, C, presses. The :on is driven by a screw, the head of which is shown at By means of this screw and the flexible bottom of the cis-, any variation in level of the mercury may be corrected.

Fig. 79.

Fortin's barometer.

The scale in this form takes its departure from a point, P, which projects downwards into the cylinder from its cover, and which may be readily seen through its glass wall. When an observation is to be made, the screw-head is turned either up or down, as is required, until this point just touches the surface of the mercury. The level of the mercury in the cistern is then at the true zero of the scale, and correct readings may be made.

The connection between the barometer-tube and the metallic top of the cistern is made by means of a disk of leather tied to each. Through the pores of this variations in atmospheric pressure are readily transmitted. When the instrument is to be transported, the adjustment screw at the bottom is to be turned until the mercury fills the cistern. The barometer may then be inclined without the mercury striking the top, it may be even turned upside down—indeed, that is the safest position in which it can be carried.

Fig. 80.

Siphon barometer.

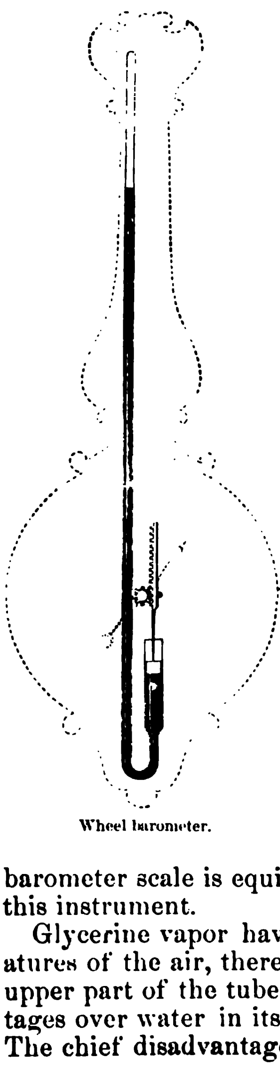
203. The Siphon Barometer.—In this the tube is bent in the manner shown in Fig. 80. It consists of a long arm A, and a short arm B. The long arm l short arm are filled with mercury. The instrument is n placed as in the figure, when the mercury takes the posi-ı shown and in the proportions given. The end of the short ı is open, air thus gains access and its variations in pressure made evident. Another form is known as Gay-Lussac's. improvement consisted in the introduction of the narrow :ube between the larger and smaller tube. The instrument ; thus made portable.

\ support and scale accompany the instrument. When a

reading is to be made, the top of the mercury in the short arm is brought to coincide with the zero of the scale. The pointer of the vernier is then adjusted to the top of the mercury in the long arm and the vernier read off.

204. The Wheel Barometer is another form of this instrument. It is not employed in scientific inquiry, but is in common use as a weather gauge in houses. It is a siphon barometer of the old form before Gay-Lussac's modification was introduced. On the mercury in the short arm there is a float, as is shown in Fig. 81. From this a rack passes upwards, which works on a toothed pinion on the axis of the index. As the mercury rises and falls in the short arm, the float and its rack also alternately rise and fall, thus the movement of revolution is imparted to the index through its axis.

FIG. 81.



Wheel barometer.

205. Glycerine Barometer.—Glycerine having about one-tenth the specific gravity of mercury, has been employed for the construction of a barometer, in which the movements on the scale may be of considerable magnitude. The vertical height of such an instrument should be about twenty-eight feet. The tube may be ordinary iron gas pipe a little over half an inch in diameter; it can thus be made to follow such irregularities of course as may be required. The upper termination should be a glass tube one inch in diameter, about five feet long, and hermetically sealed above. This is to be arranged in one of the upper stories of the building, the cistern being in the cellar. Every inch on the ordinary barometer scale is equivalent to about ten inches on the scale of this instrument.

Glycerine vapor having very low tension at ordinary temperatures of the air, there is very little backward pressure in the upper part of the tube. In this respect it presents great advantages over water in its adaptability to the purpose in question. The chief disadvantage is that it absorbs moisture from the air.

This may be avoided by covering the glycerine in the cistern with a layer of paraffine oil.

206. Errors in Barometric Readings.—1st. Lack of purity in the mercury. The presence of any baser metal as lead, tin, zinc, by altering its specific gravity, will alter the height of the column of fluid required to counterpoise the weight of the air. The mercury should be purified both by distillation and by the action of dilute nitric acid in a shallow dish.

2d. The mercury must be perfectly free from oxide or it will adhere to the sides of the glass, and the column will be too long or too short, according as it has last moved upwards or downwards.

3d. Every trace of air and moisture must be removed. This is best done by pouring a small quantity of mercury into the tube, and boiling it for some time, all air and moisture are thus driven off. When it has cooled to 100° C., or thereabouts, a second quantity of mercury warmed to this temperature is added. This is also boiled for some time; this process is continued until the tube is filled with the fluid.

4th. The tube should be sufficiently wide to allow perfect freedom of movement to the column of fluid; about half an inch in bore will answer. The instrument should be gently tapped to free the fluid from adhering to the glass whenever a reading is made.

5th. In tubes that are less than eight-tenths of an inch in bore, there is a certain error caused by capillarity. This error varies according as the last movement of the fluid was upwards or downwards. Tables for the correction of these may be obtained from special works on the subject. They may be avoided by the use of a tube with an interior diameter greater than that mentioned.

In the siphon barometer of Gay-Lussac, the long and short arm being of the same diameter, the errors on the two sides nearly counterbalance each other. A slight error, however, still remains. In one arm the movement has been upwards, and in the other downwards; consequently the curve of the surface of the mercury in the two is not exactly the same.

6th. Temperature, by expanding and contracting the volume of mercury, changes its specific gravity. This is met by correcting all barometric readings to the fixed temperature of 32° F. or 0° C.

207. Barometric Variations.—These are of two kinds. 1st. Regular or diurnal; and 2d. Irregular or accidental.

The diurnal variations are best marked at the equator. They are produced by the rotation of the earth upon its axis, whereby

one portion of the atmosphere after another is heated by the rays of the sun. So regular are these variations in the tropics that the barometer serves the purpose of a clock. At four P.M. it is at its lowest; it then rises, reaching the maximum at ten P.M.; after that it sinks, reaching the minimum at four A.M.; it then rises again, and attains the second maximum at ten A.M.

The accidental variations depend on seasons, winds, geographical situation, contour, and other causes. They are void of regularity.

From the equator towards the poles, barometric variations increase both in amount and irregularity. Rhythmic changes which are the rule in torrid regions, though they still exist in northern climes, are so masked by accidental variations that they are almost undiscoverable. At the equator ordinary variations are within one-quarter of an inch. In the region of New York State the limit is increased to an inch and a half, and at 25 degrees from the pole it reaches two and a half inches.

208. Mean Barometric Height.—From what has been said above, it is evident that this must vary for each region. It is usually given for the day, month, and year.

Mean daily height is obtained by adding together 24 hourly variations and dividing the same by 24.

Mean monthly height, by adding together the above for a month, and dividing by the number of days in the month. It is greater in winter than in summer.

Mean annual height, by adding together the preceding for one year, and dividing by 12.

At the equator the mean annual height is 758 millimetres, or 28.84 inches. Between latitudes 30° and 40°, it attains its maximum of 763 millimetres, or 30.04 inches. North of this it diminishes. At sea level the general mean is 761 millimetres, or 29.96 inches.

209. Cause of Barometric Variations.—Reviewing the account of barometric variations at the equator (207), it will be noticed that at the hours of the day when the thermometer is the highest, the barometer is the lowest, and *vice versâ*. From this it is evident that the causes of these variations are rarefaction and condensation of the air by changes in temperature. Elevation of temperature producing expansion of air, its specific gravity diminishes; it consequently rises and overflowing the cooler portions in the upper regions there is less air by weight to press, and the barometer consequently falls.

The air which has overflowed in upper regions of the atmosphere being added to that already existing in the region to

which it passes, the increased weight causes a rise of the barometer in these localities. In this manner, gigantic aërial billows are originated in the uppermost regions of the atmosphere, which, as they pass across continents and oceans, may be traced by the variations they produce in the barometer, and changes far out of sight prognosticated and their approach heralded.

210. Barometric Variations and the Weather.—When the barometer stands at about 30 inches in New York, the weather is generally fine; if it rises above this, the certainty of fine weather increases; if it falls below, the probability of rainy weather is greater. The barometer is, therefore, capable of indicating approaching changes, and for this reason, especially when in the form of the wheel barometer, is called a weather glass.

It must not be forgotten that what the barometer really indicates is the changes in the weight of the air. Change which is attended by a rise in the barometer is generally productive of conditions which prevent the precipitation of moisture; change, on the contrary, which is attended by a lowering of the barometer is usually favorable to this precipitation. It by no means follows that because the barometer falls it will surely rain. The best that can be said is, that there is strong probability of rain. The final result is largely influenced by the direction of prevalent winds. Winds which come from over the surface of warm oceans are laden with moisture, and with a falling barometer present conditions most favorable for rain or snow. Winds, on the contrary, which come over extensive areas of land, are apt to be dry, especially if they have surmounted a mountain range. Whether the barometer be high or low, the general tendency of such winds is to produce fine weather. If they are attended by a high barometer, the weather is almost sure to be fine.

211. Barometer and the Winds.—As soon as an area of diminished pressure is established in any locality, the air of regions in the vicinity will flow towards it, and currents will thus be established. These movements are called winds. The direction of a wind indicates the positions of places at which different atmospheric pressures are prevailing. A barometer, therefore, not only acts as a gauge of pressure of the atmosphere, but also as a wind gauge.

Suppose a difference of one-tenth of an inch in pressure at two observatories, one hundred miles apart. If a series of stations were established between these, and barometers ex-

amined at each, it would be found that their altitudes when mapped would form a curved line, extending from one observatory to the other. To this modern meteorologists have given the name of the *barometric gradient.* Air flows down this gradient, and thus wind is produced. If this gradient is moderate, a gentle breeze arises; if it is steep, the resultant wind is strong.

From the above facts it is evident that but little information can be derived from observations made with a single barometer. Valuable results are only to be obtained by numerous points of observations extended over great areas.

Many causes beside that of gradients intervene to modify the character and course of a wind. Among these are rotation of the earth, also the course of mountain ranges, rivers, and valleys. When we add the size and shape of areas of high and low pressure, we can form some conception of the difficulty of collating so many varying data, and making an intelligent forecast of winds and weather.

A singular fact in connection with the influx of air towards a region of low pressure, is its tendency to assume a vertical or whirling motion. Even on a small scale this tendency exists, as we have all seen in the whirling wind with which, on the approach of a thunderstorm, particles of paper, shavings, and dust are often carried to considerable altitudes. On a great scale such whirling storms constitute the tornadoes, whirlwinds, hurricanes, and cyclones of the tropics.

212. Barometer and the Death Rate.—The relations of barometric indications to diseases and the death rate have not yet received that attention from physicians which their importance demands. One of the leading hygienic factors is the proper maintenance of exhalation of vapor of water together with other gaseous or vaporous substances from the skin and mucous surface of the lungs. Anything which tends to lower the capacity of the air for moisture, or causes its dew-point and temperature to approach, must in the nature of things interfere with the facility with which vaporization takes place from both skin and lungs. The action of these great excretory organs being interfered with, certain noxious products of the economy are not properly eliminated. They, therefore, either accumulate in the system and produce blood-poisoning, or the attempt is made to cast them out through some other channel. The organ which is thus forced into vicarious action, resents the imposition, and inflammation is the consequence.

We have seen that a lowering of the mercury in the barometer is attended by a precipitation of moisture. The conditions of which we have just been speaking are, therefore, present; inter-

ference to a greater or less extent with the functions of the system must follow. To persons who are already enfeebled by protracted disease, or who are still struggling with some fearful inflammation, a sudden fall in the barometer may bring disastrous consequences. Had the physician been forewarned of an approaching change, he might have been able to meet it by suitable remedies, and aided his patient to tide over the crisis. It, therefore, appears to be both wise and proper that more attention should be paid to this subject. If physicians would supply themselves with these instruments, and make even a passing study of their relations to disease, fewer mistakes in prognosis would be made, and many a one who otherwise passes away without warning, would be enabled to set his house in order.

CHAPTER XV.

MEASUREMENT OF PRESSURES AND ALTITUDES.

Boyle's or Mariotte's law—Open compression manometer—Closed compression manometer—Exhaustion manometer—Equality manometer—Exhaustion water-valve—Aneroids—Determination of altitude by aneroid or barometer—Error in barometric determination of altitude—The barometer in mines—Pressure and solubility of gases—The Windmill—Conveyance of germs by air.

213. Boyle's or Mariotte's Law.—We have seen that the barometer is essentially an instrument for measurement of pressure, but its indications are limited to one atmosphere, or about fifteen pounds to the square inch. It is often necessary that pressures surpassing this, sometimes even a hundred-fold, should be determined; for this purpose various kinds of manometers, as they are called, have been contrived. They depend upon a general law of the expansion and contraction of gases, or on the action of springs.

Boyle's or Mariotte's law deals with the compressibility of gases. It was discovered by Boyle in 1662, and passes under his name in England. In 1679 it was discovered independently by Mariotte, and is known as his law on the Continent. We have seen (160) how the volume of this form of matter changes

under variations of pressure. To measure these changes, Boyle contrived the apparatus represented in Fig. 82. It consists of a stout tube about four feet in length, hermetically sealed at one end, open at the other. It is bent so that the closed extremity forms the short arm.

FIG. 82.

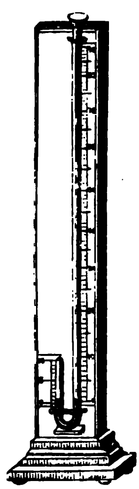
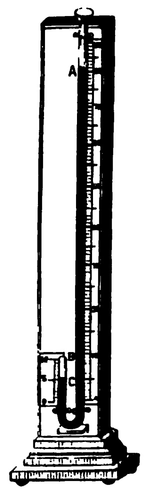


FIG. 83.



Mariotte's or Boyle's law.

When it is to be used sufficient mercury is poured into the bend to fill it to the zero of each scale. A column of air is thus confined between the surface of the mercury in the short tube, and the closed extremity of the tube. When more mercury is poured into the long arm, pressure is brought to bear upon the mercury in the bend, and so upon the short column of air. As the mercury in the long arm rises inch by inch, Fig. 83, shrinkage takes place in the length of the column of air in the short arm. At last when the column of mercury in the long tube A B has reached an altitude, A, of 30 inches above that in the short arm, the air in the latter is submitted to a pressure of one atmosphere, and will be found to have diminished to one-half its first volume, as at C.

At the commencement of the experiment the column of air in the short arm was already under the pressure of the normal atmosphere; addition of an atmosphere of pressure exerted by the column of mercury increases it to a pressure of two atmospheres. We, therefore, learn that by doubling the pressure on a gas it shrinks to half its volume. If the length of the long arm is sufficiently increased, and atmosphere after atmosphere of pressure added, the shrinkage of the column of air continues at a fixed rate. With three atmospheres of pressure it is one-third; ten atmospheres, one-tenth of the original volume. This rate of contraction has been verified by Dulong and Petit up to twenty-seven atmospheres.

From the account given, the law of the volume of gases may be briefly stated as follows: *The temperature remaining unchanged, the volume of a stated quantity of a gas is inversely as the pressure.*

For pressures less than one atmosphere the law also holds good. Diminution of the pressure to one-half, the volume is doubled; to one-tenth, the volume is ten-fold, and so on. The experimental demonstration of this fact may be obtained by the

apparatus, Fig. 84. B C is a deep, wide glass tube with a funnel-like mouth above. The tube and funnel are filled with mercury to the line indicated in B. In the mercury of this deep pneumatic trough a tubular bell-jar, A, is immersed. In this tube bell a column of air of known length is enclosed. When the mercury is at the same level in the tube, and in the pneumatic cistern, the air in A is under a pressure of one atmosphere. If the tube is raised so that there is a difference of 15 inches between the level of the mercury in it and in the tube trough, the pressure on the air in the tube receiver will be reduced to one half, and the column of air will be double the length it had previously.

FIG. 84.

Expansion with diminished pressure.

While the law of Boyle is sufficiently exact for all ordinary purposes, it is not absolutely true. Despretz found that when examined side by side in tubes exposed to exactly the same conditions, carbonic acid gas, sulphuretted hydrogen, ammonia, and cyanogen, were more compressible than air. Up to 15 atmospheres, hydrogen follows the law for air; beyond that it is less compressible. Even for air the law is not absolute, for Cailletet has examined it up to 600 atmospheres of pressure, and finds that up to 80 atmospheres it has a maximum relative compressibility; after that it becomes less compressible, the compressibility diminishing more rapidly than in the case of hydrogen.

As a rule, all gases deviate from the law as they approach their point of liquefaction. The greater the distance from this point, the more closely do they follow the law.

FIG. 85.

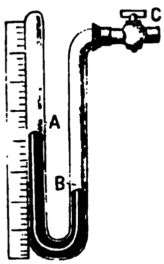
Open compression manometer.

214. Open Compression Manometer. — In its simplest form this instrument consists of a bottle or reservoir, A, nearly filled with mercury, and tightly closed by a screw stopper. Through this the tube B passes. It is over 5 feet in length, open at both ends, and dips into the mercury, nearly touching the bottom of the bottle. A second tube, C, passes through the side of the bottle; this is to be connected with the boiler or other apparatus in which the gas or vapor is generated. Through

the tube C the gas exerts its elastic force upon the surface of the mercury in the bottle. The mercury is consequently pushed up the tube B, and continues to rise until the column of fluid balances the pressure exerted by the gas or vapor. The height of the column is then read off in inches of mercury, or it may be given in atmospheres or fractions thereof. It may also be expressed in pounds to the square inch. This form can only be used for moderate pressures, the great length of tube required for high pressures rendering it too inconvenient for practical use.

215. Closed Compression Manometer.—A simple form of this instrument is represented in Fig. 86. It consists of a thick glass tube of uniform diameter closed at one end and bent as at A, B, C. The bend is filled with mercury. The space A is filled with air. The stopcock C is connected with the apparatus in which the pressure is generated.

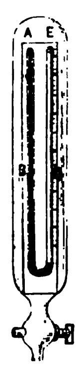
Fig. 86.



Closed compression manometer.

As the pressure in the generator, a steam boiler for example, increases, the column of air A diminishes. When, according to Boyle's law, it has reached one-half its original length, the pressure is one atmosphere in addition to the air pressure, and so one to one-tenth for ten atmospheres, and one-hundredth for one hundred. Since the increase in pressure in the boiler is partly counterpoised by the increasing weight in the column of mercury that attends its increase in height, the error that is thus introduced must be corrected. This is a mere matter of calculation, and is best done in the preparation of the scale which is attached to the instrument, and by which its indications are observed.

Fig. 87.



Exhaustion manometer.

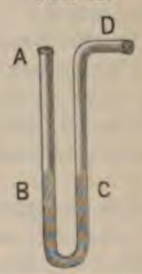
216. Exhaustion Manometers.—For the measurement of perfection of a vacuum, any of the forms of barometer we have described will answer. In practice, however, it is found that the mercurial barometer is very inconvenient on account of its length and fragility. To avoid these objections the adjoining contrivance, or exhaustion gauge, is employed. It consists of a tube closed at A, and open at E. The arm B D is filled with mercury, all air and moisture being carefully expelled. The height of the apparatus is about eight or ten inches. The tube is attached to a scale, and both are enclosed in a stout glass cylinder fitted into a brass cap below by which it may be attached to an air-pump, vacuum pan, or other

apparatus, in which the perfection of the exhaustion is to be measured.

The working of the instrument is as follows. The top of the column of mercury in A having an altitude of eight inches above the level of that fluid in D, when the exhaustion falls below eight inches of mercury in the barometer, the mercury at A begins to leave the top of the tube. The exhaustion being pushed it falls lower and lower, until when a perfect vacuum is approached it stands at very nearly the same level in both arms of the tube. If the gauge has been perfectly freed from air and moisture when the mercury was introduced, the level B will never fall exactly as low as that in D. If it does fall as low, or even lower, it shows that the construction of the instrument is not perfect. Intermediate pressures between 8 inches and a vacuum, are indicated by the difference between the levels of the mercury of the two arms.

217. Equality Manometer.—It often happens that in physiological inquiries it is necessary to know whether the contents of an air-chamber or bell are under the same pressure as the then prevailing atmospheric pressure. This is determined by a gauge of the form represented at A B C D. It is a tube open at both ends and bent in the manner shown. The extremity D is attached to the chamber or air-bell. The bend is filled to the height B C with mercury, water, or ether, according as greater delicacy is required. The mouth A offering free communication with the air, any increase in pressure in the jar over that of the air, will be shown by a rise of the fluid above B, any decrease by its fall.

FIG. 88.



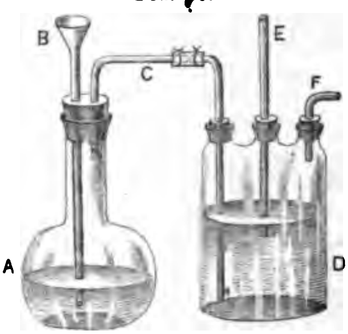
Equality manometer.

218. Exhaustion Water-valve.—In the preparation of solutions of ammoniacal and other gases, in water, and also in washing gases, it not unfrequently happens that partial vacua are suddenly formed in some part of the apparatus, and the contents of a washing bottle or the freshly formed solution is drawn into another part of the apparatus and lost.

To illustrate this let A, Fig. 89, represent a flask in which ammonia gas is in process of generation from aqua ammoniæ. It is supplied with a safety tube B, which is open at both ends and dips below the surface of the liquid A. The gas, as it is generated, cannot escape up this tube, for its mouth is closed by liquid. It, therefore, passes by the tube C to the bottom of the three-necked bottle, and bubbles through the water D contained therein. Any portions that escape solution in D, pass out

through the escape tube F into a second bottle, and so on through a train of half a dozen or more. Each of these bottles is provided with a safety tube E open at both ends, and dipping a short distance under the fluid it contains.

Fig. 89.



Exhaustion water-valve.

Let us suppose that from any cause the space above the water in the bottle D becomes exhausted, the tendency would be to draw water from the next bottle through F, and so injure the solution already formed. This, however, does not happen, for the moment the exhaustion reaches a certain point air rushes down the tube E, and any further increase of vacuum is prevented.

In like manner formation of a vacuum in the flask A is immediately checked by an ingress of air through its safety tube B, and loss of any part of the solution already formed in D prevented.

In the preparation of oxygen and protoxide of nitrogen for the purposes of respiration, careful purification of these gases by washing them with various solutions is indispensable. Each bottle in the series should be provided with safety tubes like those represented.

219. Aneroids.—These are instruments for the measurement of pressure, and having an appearance similar to that of a watch with its graduated face and hands. They vary in size from that of a lady's watch to that of an ordinary clock. They derive their name from α, without, and ὑγρός moisture, indicating the fact that liquid does not enter into their construction. They are of two kinds, the first for the measurement of pressures beyond that of the atmosphere, the other for those that are less; the latter is called the aneroid barometer.

The aneroid barometer consists of a metallic drum, the heads of which are made of very thin corrugated metal. The interior of the drum is exhausted; the heads are consequently forced inwards by the pressure of the air on the outside. Any diminution in this pressure causes the drum heads to recede from each other, partly by the elasticity of the corrugated metal, and partly by the action of a spring. Any increase of pressure, on the contrary, causes them to approach. By means of a delicate system of levers, these movements are multiplied and brought to act upon the hands, just as in a watch the movements of the

main spring are by a series of wheels brought to bear upon its hands.

Instruments of this description are constructed by Casella which possess marvellous delicacy. Their portability gives them a great advantage over the mercurial barometer. The only difficulty is, that the multiplying machinery is liable to get out of order; hence it is necessary to compare their indications from time to time with those of a good barometer. Especially are they apt to give false indications when they have been submitted to sudden and unaccustomed changes of pressure.

By reversing the construction of the aneroid barometer, and admitting gas or vapor to the interior so that it may exert its elastic force therein, the instrument is converted into a gauge for measurement of compression or condensation. In this form it is now found attached to steam boilers, and may be said to be the ordinary steam-gauge.

220. Determination of Altitude by Aneroid or Barometer.—The experiment of Pascal demonstrated not only the point of which he sought proof, viz., that air exerted pressure, but also, that the higher a barometer was taken above the surface of the earth the lower did its mercury stand. This fact offers a method by which the altitude of a mountain, and even of lesser elevations may be determined.

In examining the extent to which the barometer might be used for this purpose, one of these instruments was carried from the level of the water in the Thames to the top of St. Paul's Cathedral. The mercury fell nearly half an inch, the ascent being 450 feet. On the summit of Mt. Blanc the fall is fifteen inches the elevation being about 15,000 feet; from this it follows that one-half of the whole weight of our atmosphere is embraced in a layer about three and one-half miles thick on the surface of the globe.

In estimating the height of a mountain by barometer, observations should be made at the base and the summit at the same time. Corrections must be made for the effects of temperature on the two columns of mercury, and also for differences in gravity.

By the use of the aneroid barometer for this purpose many of the errors which arise with the mercurial barometer may be avoided. The facility of conveyance is also an especial advantage which the aneroid enjoys.

221. Errors in Barometric Determinations of Altitude.—These have amounted to as much as one-twenty-third of the whole height. Ruhlman has shown that the cause of this error is that

the mean of the temperature at the two stations, as indicated by thermometers, was not the actual mean of temperature of the air between these stations.

That thermometers do not give the true temperature of the air is owing to the fact that their indications are affected by radiations from the earth and from objects in their vicinity. In the management of meteorological observations more attention should be paid to this fact.

222. Barometer in Mines.—As ascent above the earth's surface produces a fall in the barometer, so a descent beneath its surface produces an increase in the altitude of the mercurial column. Variations in the barometer in coal mines in which *fire-damp* or carburetted hydrogen escapes, are of especial value to the miner, since they afford him the means of knowing whether this dangerous gas is escaping from the crevices in which it is confined. When the pressure of the air is high, carburetted hydrogen is forced back into the crannies in which it is generated. When the pressure falls, it then by its elastic force presses its way out, escapes from its hiding places and becoming mingled with the air of the mine, forms therewith a dangerous explosive mixture. It also exerts a poisonous action on the systems of those who are obliged to breathe it, and is, therefore, doubly dangerous and objectionable.

223. Pressure and Solubility of Gases.—Place a glass containing cool freshly drawn water under an air-pump bell and throw the pump into action. As the pressure diminishes, the water will become milky in appearance. This loss of transparency is produced by the formation of myriads of minute bubbles of air or water gas, which the water held in solution at the ordinary pressure, but which it was unable to retain when the pressure fell.

Reversing the above experiment and exposing water to a gas under pressure, it is found that it takes up a larger proportion of gas than at the ordinary atmospheric pressure. This fact lies at the basis of the explanation of the formation of all natural and artificial effervescing waters as well as of effervescing wines. As might be expected, the amount of gas a fluid will hold in solution is determined by Mariotte's law.

As an example of the facts in question, we find that at ordinary pressures and temperatures water will hold about its own bulk of carbonic acid gas in solution. If the gas is freely supplied at a pressure of, say, four atmospheres, and the solvent action of the water promoted by gentle agitation, the water will take up the same bulk of gas as before, but this gas will be denser than in the preceding case, and there will really be four

times as much in the water as when the solution was made at the ordinary atmospheric pressure. That this is the explanation is shown by relieving the water from pressure, when at once it surrenders its excess of dissolved gas, a violent effervescence being produced.

It is worthy of mention that when the air dissolved in water is removed therefrom, by submitting it to the action of a vacuum, it assumes an insipidity similar to that of pure distilled water. When it has regained its original supply of gas, its flavor returns. This would seem to show that though oxygen is generally stated to be without effect on the sense of taste, there is something in connection with its action which enables us to detect its presence in the free state in water, or, we might better say, its absence.

224. **The Wind-mill.**—As the force of moving water is applied as a motor in various kinds of water wheels, so that of wind is utilized in the wind-mill. This form of apparatus is extensively employed for purposes of drainage in Holland. It is also used in mills for grinding grain. In the western regions of the United States it is applied for purposes of irrigation. To physicians it is of interest in connection with its use as a motor for pumps or other hydraulic apparatus employed in raising water or removal of drainage and sewage.

225. **Conveyance of Germs by Air.**—In closing this division of our subject, we desire to add a few words regarding the conveyance of germs by the air. If pure distilled water is exposed to air, after a while it is found to contain various forms of microscopic beings, some of which belong to the plant and some to the animal kingdom. For long it was a matter of dispute as to whether these were produced by *spontaneous generation* or were conveyed to the fluid by the air in the form of exceedingly minute germs or spores. It is clear that there is no half way between the two theories.

After innumerable experiments it is now generally admitted that the floating particles in air, which appear to us as the motes that dance in the sunbeam, are the medium by which these spores or germs are carried. It is true we may not be able to discover the germs themselves on account of their minuteness, but of their presence and existence there can be no doubt. If air is filtered, by passing it slowly through a long column of cotton in a glass tube, and then admitted to a flask containing pure water, the appearance of vegetable and animal life is greatly hindered or entirely prevented. If, at the same time, a jar in the immediate vicinity is supplied with air at the same

rate and in the same manner, but of which there is no filtration, organized beings appear in the usual way.

If spores and germs capable of initiating constructive changes which result in the production of organized beings can be so small as to be undiscoverable even by the microscope; if, moreover, such germs are conveyed by the air, there is certainly nothing objectionable in the proposition that disease germs may both exist and be conveyed in the same manner. See Schizomycetes (601 A). It is scarcely a valid objection to such a theory, that disease germs may be supposed not to have any existence. There are many facts which show that they do exist, and that in some cases, at least, they are the agents of retrograde or destructive metamorphosis, just as other germs are agents of constructive metamorphosis.

Many diseases, and among them those known as malarial, are conveyed by winds to a distance from the place of generation. Not infrequently a fringe of certain trees will act as a complete barrier to the passage of such emanations. The most rational explanation of such a fact is that in passing among the leaves of the trees, the air has undergone a removal or destruction of the agent, spore or otherwise, which originates malarial trouble in the body. It is easy to imagine that in this case the spores are destroyed or paralyzed by the emanation of the plant to which they are exposed as they pass among its leaves. Absence of malarial disease in regions occupied by terebinthine or pine trees, would tend to show that the result is probably owing to the action of ozone.

The destruction of germs attached to motes in the air may in other cases be very difficult of accomplishment. It has been found, in the management of disinfectant apparatus attached to quarantines, that a temperature of 212° F. or the boiling of water does not always destroy germ life. To insure this result, a temperature of 250° F. or even higher is requisite. This may be readily attained by means of an oven or by high pressure steam. In all cases of death by diseases in which there is any probability of conveyance by germs, the physician should see to it that all articles of clothing are destroyed or at least submitted to a temperature of 300° F.

The dust which settles on the walls of rooms is often an unsuspected agent in the conveyance of disease germs. The passage of an affected person may have left them in the air. They have thus become attached to the floating motes and so to the walls. Here they may remain for a long time, until by some cause they become detached and, gaining entrance to a human body, initiate the peculiar train of symptoms which they are capable of producing. A thorough cleansing of the walls of rooms is the only safeguard against this source of infection. The

good that is accomplished by such cleansing is shown by the change in odor of a room after it has been thoroughly cleaned.

With increase in the penetrative and magnifying power of microscopes, it is not improbable that light will be thrown on this question of the propagation of certain diseases by special spores or germs. In connection therewith, we may mention a device which offers some opportunity of entrapping these objects for examination. It consists of an aspirator (171) by which air is drawn through a tube which is loosely packed with fine gun-cotton. As is the case with ordinary cotton, this entraps the floating motes. To separate these from the gun-cotton, the latter is dissolved in ether, and a very dilute collodion formed; in this the motes sink and may be prepared for examination under the microscope in the usual way.

CHAPTER XVI.

PHYSIOLOGICAL AND THERAPEUTICAL EFFECTS OF VARIATIONS IN DENSITY OF AIR.

Composition of blood—Hæmoglobin—Divisions of physiological effects of pressure—Tension of oxygen or other gas respired—Diminution of pressure below one atmosphere—Mal des Montagnes—Symptoms of Mal des Montagnes—Theoretical explanations of Mal des Montagnes—Theory of M. Jourdanet—Balloon sickness—Bert's rarefaction cylinders—Air in caves—Death from diminished air pressures—Increase of pressure above one atmosphere—Respiration of pure oxygen—Physiological action of moderately condensed air—Action of oxygen under high tension—Oxygen poisoning—Relation of animal tissues to oxygen—Death from increased pressure—Therapeutical effects of respiring oxygen—Therapeutical uses of compressed air—Hygienic management of compressed air—Impurities in compressed air—Effects of decompression—Nature and treatment of decompression accidents—Relation of barometric variations to natural history—Bert's résumé of his results.

To place this important matter in as clear a light as possible it is necessary that we first examine briefly into certain characters of the blood, the chief circulating fluid of the body.

226. **Composition of Blood.**—In all the higher animals blood consists essentially of two parts: 1st. A fluid portion called plasma, composed of water, albumen, fibrin, and other organic

bodies, together with various inorganic salts. 2d. Corpuscles or globules; these are of two kinds, white and red. White globules are the mother cells of the red corpuscles, and the latter are carriers of oxygen from the lungs to the system. It is with the latter that we are at present especially concerned; their composition, according to condition, is as follows.

Wet Corpuscles.		*Dry Corpuscles.*	
Water	56.5	Hæmoglobin	90.54
Solids	43.5	Proteids	8.67
		Lecithin	.54
	100.0	Cholesterin	.25
			100.00

227. Hæmoglobin.—The chief constituent of red blood cells may be readily obtained therefrom by breaking up the cell wall either by alternate freezing and thawing, or by addition of chloroform or of bile salts. In some creatures it is crystalline and in others amorphous. According to Hoppe-Seyler, its composition in the dog is

Carbon	53.85
Hydrogen	7.32
Nitrogen	16.17
Oxygen	21.84
Sulphur	0.39
Iron	0.43

In addition there is about 3 or 4 per cent. of water of crystallization. Besides the ordinary elements in proteid bodies, hæmoglobin contains iron, to which element doubtless its special properties are due. It is readily soluble in warm water, the solution having a bright arterial color. Even though very dilute this solution gives a characteristic spectrum, a part of the red and the greater portion of the blue being absorbed, and two strongly marked absorption bands appearing between the solar lines D and E.

When crystals or solutions of hæmoglobin, prepared as above, are placed in the vacuum of the mercurial air-pump they give off a definite proportion of oxygen gas, viz., 1.76 cubic centimetre per gramme, or 1.34 under a pressure of one metre. This oxygen is entirely independent of that entering into the composition of the substance. It is loosely associated with it, and may be added to or dissociated therefrom at pleasure without injury.

The associated oxygen of hæmoglobin in solution may be separated by other means than the vacuum; among these are hydrogen, other gases, and various reducing agents as ammonium sulphide.

Hæmoglobin which has lost its associated oxygen, loses its bright scarlet color, the crystals become darker and of a purple tint. They are also dichroic, the thin edges appearing green and the thicker parts purple. The solution shows a similar change of hue, passing from light scarlet to a purplish claret tint when examined in thick layers, but green when in thin.

The spectrum of reduced hæmoglobin is entirely different from that which contains oxygen. The two absorption bands of the latter have disappeared, and in their place a single broader but fainter band has come into existence. The blue also suffers less absorption by reduced hæmoglobin (650).

When reduced hæmoglobin is exposed to oxygen or to air containing oxygen, it immediately absorbs that gas, and if it is present in sufficient quantity takes up its full complement, one gramme of crystals associating to itself 1.34 c. cm. of oxygen.

To hæmoglobin which contains associated oxygen the name of *oxyhæmoglobin* is given. When this has suffered a dissociation of its oxygen, it is called simple or reduced hæmoglobin.

The facts we have hereby acquired enable us to comprehend the role which the red corpuscles play as carriers of oxygen. Their function is accomplished by virtue of their hæmoglobin. In the lungs they associate oxygen to themselves, and carrying it into the innermost parts of the system, it is there dissociated by virtue of the looseness with which it is held. Thus alternately the corpuscles receive and surrender oxygen, and the demand for oxygen by the system is supplied.

In a similar manner hæmoglobin combines with carbonic acid. This case, however, differs essentially from that of oxygen, for with the latter scarcely any of the gas is held in the plasma, nearly all is in the hæmoglobin. In the case of carbonic acid, on the contrary, the plasma contains as large a per cent. as the corpuscles.

228. Divisions of Physiological Effects of Pressures.—Understanding the agency by which oxygen is conveyed into the interior of the body, we are prepared to examine the complex effects of variations of pressure upon this act with a fair degree of intelligence, and with some prospect of arriving at a correct solution of the phenomena which present themselves.

For sake of convenience the subject may be studied under two divisions:

1st. Diminution of pressure below one atmosphere.

2d. Increase of pressure above one atmosphere.

For the facts we are about to give, science is largely indebted to M. Paul Bert, from whose work on "Barometric Pressures" we have made the abstract presented in this chapter. The impor-

bodies, together ... the field it opens, cannot
or globules; these ... give their attention thereto.
globules are the ...
latter are carriers of ... Gas Respired.—The term ten-
is with the latter ... work; its significance is both
their composition ... combines two factors: 1st. The
... 2d. The pressure in atmos-

Wet ...
Water ...
Solids

... being 20.6 and the pressure
... 20.6. This is the standard or
... various departures, for example,
... same, the pressure may increase.

227. H...
may be ...
either ...
roform ...
others ...
in the ...

	Percentage.		Pressure.		Tension.
.	20.6	×	2	=	41.2
.	20.6	×	5	=	103.0

... are respiring normal air under a
... is virtually introducing into its
... were respiring pure oxygen at a
...

	Percentage.		Pressure.		Tension.
...	20.6	.	5	=	103.0
...	100.0	.	1	=	100.0

... pressure reduces tension, for ex-

In ...

Percentage.	Pressure.		Tension.
20 ...	...	=	10.3
20 ...	...	=	4.1

... BELOW ONE ATMOSPHERE.

... By ascent of a lofty mountain:
... Mountain sickness ... appear. 2d.
... In exhausted re-
... the percentage of oxygen in
... the normal of 20.6, even
... atmosphere. Reduction of
... reduction in pressure:
... the percentage

... generally suffer from this
... They seldom reach
... On the other hand

Gay-Lussac, Glaisher, Burrall, and Bixie, suffered but little at an altitude of 23,000 feet.

The causes of these differences are numerous. One fact seems to be pretty well marked, and that is, that the peculiar physiological effects begin to appear about 1700 feet above the line of eternal snow. Though there are many exceptions to this, yet it may be said that the more elevated the line of snow, the higher can the traveller ascend without suffering from Mal des Montagnes. Much depends upon the condition of the person himself, great difference appearing in different ascents of the same mountain, though he is not conscious of any material difference in his condition.

232. Symptoms of Mal des Montagnes.—*Digestion.* Very little appetite, one-third or one-fourth the usual amount of food satisfies hunger. Thirst, distaste for food, and even for its sight and odor; insipidity of fluids, nausea, vomiting, are experienced by nearly all. Not only are phlegm and bile thrown up, but also blood, and the irritability of the stomach is sometimes so great that not even a teaspoonful of water can be retained. Escape of bile into the intestine during the paroxysms of vomiting brings on diarrhœa, which is aggravated by the intense cold and unavoidably wet feet.

Respiration becomes short, frequent, difficult, and interrupted. The oppression in the chest is often attended by severe pain. This with exaggerated fatigue constitutes generally the first evidence of Mal des Montagnes. Animals suffer equally with men.

Circulation. Acceleration of the pulse, though not so frequently mentioned by authors as the respiratory and digestive symptoms, is nevertheless not less constant. The record is as high as 140 and 150 beats for great altitudes. Acceleration of the pulse is not transitory, it continues throughout the sojourn at great elevations. Its force also diminishes, it becomes irregular, more compressible, and smaller.

The venous system shows fulness of the vessels, congestion of the skin, lips, conjunctiva. Suddenly these sometimes give way to a death-like pallor, menacing syncope and complete loss of consciousness. To this train of symptoms hemorrhages from nose, lungs, eyes, lips, ears, intestines, and kidney are occasionally added.

Locomotion. One of the earliest signs is a sense of extreme weight in the lower extremities, a fatigue having no relation to the work done. The strongest and most experienced walkers can only take a few steps at a time. Not only walking, but any form of exercise becomes almost impossible.

Innervation. Fearful headache, as though the head were bound in a fillet of steel; intellectual depression; buzzing in the ears; dulness of taste and smell; sometimes dimness of vision, somnolence, and syncope.

Aëronauts experience similar symptoms. The moral faculties suffer before the physical; memory is obscured; the management of the balloon is forgotten; the members fall asleep. At great altitudes insensibility often comes on suddenly.

233. Theoretical Explanations of Mal des Montagnes.—Of these there are two groups; one presents so curious a list of absurdities that we quote it. The other deals with the mechanical, physical, and chemical effects which attend changes in barometric pressures.

In the first category we may mention pestilential exhalations, electricity, deficiency of oxygen, fatigue, cold, diminution of the weight supported by the body, escape of gas from the blood, dilatation of intestinal gas, relaxation of the hip-joint (Humboldt), excess of carbonic acid. From these fanciful explanations, we turn to the

234. Theory of M. Jourdanet, who reasoned that whatever might be the affinity of blood corpuscles for oxygen during respiration, it was evident that in air poor in oxygen the amount of that gas taken up by the blood would be less. In the rarefied atmospheres of mountains there is less weight of oxygen in each inspiration, therefore the blood is not so rich in that gas as at the sea level. This poverty in oxygen is exactly the same as though the number of blood corpuscles was reduced, and the consequences are also the same. An ascension of 10,000 feet gives a barometric deoxygenation of the blood, just as bloodletting gives a corpuscular deoxygenation, and when pushed to an extreme they are alike fatal. At moderate altitudes, like the great Mexican plateau, the difference in richness in oxygen is not sufficient to attract attention under ordinary conditions; but when disease attacks the people of these plateaus, the physician quickly recognizes the fact that it is invariably of an anæmic type, the result of deficient supply of oxygen.

235. Balloon Sickness presents the same symptoms as Mal des Montagnes. It comes on in aëronauts later than in those who ascend mountains, because the former reserve the force which the latter have spent in making the ascent. A similar lack of force results from a sleepless night, indigestion, or any indisposition. The tired man and the sick man are both subjects for Mal des Montagnes or balloon sickness.

Crocé-Spinelli and Sivel, in their first high ascent, observed that at an altitude where the mercury stood at 300 millimetres, they experienced more discomfort than when in Bert's receivers. This they attributed to the greater amount of muscular exertion, to the great depression of temperature, and the length of their sojourn in the attenuated strata. Regarding inhalation of oxygen at great altitudes, they say "we direct special attention to the favorable effects of the respiration of oxygen under diminished pressure. Return of strength and appetite, diminution of headache, reëstablishment of clear vision, and coolness of nerves." All these phenomena they had already observed in Bert's cylinders.

236. Bert's Rarefaction Cylinders.—For the apparatus by which he conducted his researches, M. Bert tells us he was indebted to M. Jourdanet. For diminished pressures the apparatus consisted of two large cylinders which communicated by a door. They were nearly seven feet in height and more than three feet in diameter. The exhausting pump was driven by a Lenoir gas engine. A pressure of 250 millimetres could be obtained in twenty minutes.

FIG. 90.

Rarefaction cylinder.

In this apparatus Bert verified the symptoms which have been given as mountain sickness and balloon sickness. It was shown that they originated in a deficiency of oxygen in the blood, caused by its diminished tension in the air respired. Regarding balloon sickness, he says:

"At half an atmosphere of pressure everything must be doubled to secure the same introduction of oxygen as at the level of the sea. Not only must the respiratory movements be increased in force and rapidity, but the heart beats must be doubled in force and intensity. This is clearly impossible, consequently the percentage of oxygen in the blood diminishes, on this there follows diminished activity of the respiratory muscles; the amplitude of the inspiratory act becomes less and less. The same happens with the beating of the heart. The pulsations may be more frequent, but the force of its action is greatly diminished. In like manner the functions of every organ are interfered with."

237. Air in Caves.—It sometimes happens that in caves and mines in which sulphides are present, the oxygen of the air uniting with the sulphur in the pyrites undergoes a gradual removal, and the composition of the air becomes seriously altered. As an example of this the following analysis of the air of a deep cave near St. Maurice is given:

Nitrogen	82.66
Oxygen	15.33
Carbonic anhydride	1.99

In this case, the tension of the oxygen is about 15 compared with that of air at 21. It is equivalent to an elevation of 6500 feet, and not unfrequently produces symptoms similar to those of Mal des Montagnes. It is recorded that in a copper mine near Cam-Brea the oxygen tension is only 14.5.

238. Death from Diminished Air Pressure.—In ordinary air and in mixtures, death ensues when the tension of the oxygen is reduced below 4, or for normal air to a pressure of one-fifth of an atmosphere. With diminished pressure, the percentage of gas in the blood diminishes also, but in a little less proportion than the law of Dalton would show. The blood also loses relatively less oxygen than carbonic acid.

An animal placed in a closed vessel, an animal respiring in a current of air the proportion of oxygen in which is steadily diminishing, an animal respiring air the pressure on which is steadily diminishing: all three die in the same manner, viz., by true asphyxia.

Increase of Pressure Above One Atmosphere.

239. While the earth presents great elevations, by the ascent of which the effects of diminished pressure may be observed, it does not present depressions of sufficient extent to enable us to study those of increased barometric pressure. The only depressions of any consequence are the Dead Sea and the Caspian region; in these the depression is so insignificant that it may be disregarded. Mines and caves might give greater tension by increased pressure, but any increase in these instances is apt to be compensated by a poverty in oxygen (237).

The actual conditions under which increased pressure arises are consequently artificial. They are 1st. Descent in the diving-bell; 2d. Descent in the diving-dress; 3d. Working in caissons used in construction of piers for bridges, in deep water; 4th. Sojourn in the condensing cylinders of aëropathic establishments.

240. Respiration of Pure Oxygen.—Though oxygen is the constituent of air which supports the function of respiration, it has been shown by direct experiment that hot-blooded animals can endure the respiration of pure oxygen but for a comparatively brief time.

In natural respiration the oxyhæmoglobin in the arterial blood is never completely saturated with oxygen. In respiration of pure oxygen it becomes in time completely saturated, and the venous blood also takes on the arterial hue. When this occurs the functions of the body are seriously disturbed.

In the case of respiration of pure oxygen, the tension of the gas is 100. If the gas be breathed under a pressure of three atmospheres, the tension is equivalent to 300, and the gas acts as a virulent poison, quickly producing convulsions which terminate in death.

By increasing the pressure on air to about five atmospheres, its tension becomes 100, and its physiological action when breathed is the same as that of pure oxygen. Increasing the pressure rapidly to 15 atmospheres, the tension becomes 300, and it has the same poisonous action as oxygen under a pressure of three atmospheres.

Air below a pressure of five atmospheres may be breathed for a short time, and if the pressure is only two or three atmospheres, it may be respired for a considerable time, and often with excellent effect. We may, therefore, study the action of compressed air in two states: 1st. Under moderate pressures; 2d. Under high tension, or over five atmospheres of pressure.

241. Physiological Action of Moderately Condensed Air.—Under a tension of from 30 to 60, the following conditions appear. The list is taken from the experiments of Vivenot.

1st. Noises in the ear, arise also in decompression, from stoppages in the Eustachian tube; are relieved by swallowing, and by blowing strongly into the tube, at the same time holding the nose and shutting the mouth.

2d. Change of voice, higher note; nasal, difficult pronunciation; impossible to whistle or hiss; sometimes stuttering.

3d. Smell, taste, and touch obscured.

4th. Expansion during inspiration, and compression in exhalation increased.

5th. Diminution in abdominal convexity by compression of intestinal gas.

6th. Diaphragm and base of lung lowered.

7th. The lung during inspiration, as well as expiration, in front of the heart.

8th. Hence diminution of cardiac impulse on palpation, and diminution of its sounds on auscultation.

9th. Vital capacity of the lungs increased.

10th. Return to normal pressure; the vital capacity falls belov the normal. The lung does not for a time regain its primitiv volume.

11th. Repeated sojourns in the apparatus each day cause ir creased pulmonary capacity. After 3 months of air baths one-half hour each day, pulmonary capacity was increased on quarter without any diminution of contractile power in the lun

12th. The habits acquired by the diaphragm and thorax co tinue after completion of the experiments.

13th. These increments are common both to extreme ai ordinary respiration.

14th. Respiration less frequent by 1 to 4 movements p minute.

15th, 16th, 17th, 18th. Repeat for frequency what has be said for depth from 10 to 13.

19th. Inspiration is quicker, expiration slower; at first quic then so slow as to have the appearance of a pause.

20th. Increase in proportion of carbonic acid. With atmospheres there is 22 per cent. more of carbonic acid than the normal pressure.

21st. This augmentation is not in the same ratio of increa as that of pulmonary capacity.

22d. It is common both to forced and tranquil respiration.

23d. Comparing the increase of carbonic acid with the minished frequency of respiration, it is evident that the increa is due to the greater absorption of oxygen.

24th. Consequently after a series of sojourns in condens air, the venous blood becomes clearer, the temperature ris muscular force is increased, hunger is greater. Though mc nutriment is taken, the body becomes lean. If, on the contrai the pressure is very moderate and a great deal is eaten, a pers may fatten.

25th. Frequency of pulse diminishes 4 to 7 in the minu the diminution being greater when there has been an abnorm acceleration.

26th. Return to air restores the normal rhythm of the puls

27th. If the frequency of pulse has been caused by respirato trouble, a permanent lowering follows treatment by compress air.

28th. Diminution in frequency of pulse seems to be mere a result of the mechanical action of compressed air. The i creased pressure increasing the resistance to the arterial wav from the heart, the number of pulsations is consequently minished.

29th. The curve of the radial pulse presents changes in forı Its height diminishes, the line of ascent is less rapid, mo

oblique, the summit straight or slightly convex. There is diminution in the capacity of the vessels and of the quantity of blood they contain; increase in the systole of the heart, and greater obstruction in the capillary circulation.

30th. With return to normal air, sphygmographic tracings assume their normal character.

31st. The radial pulse is changed to the touch; it becomes small, thread-like, almost imperceptible.

32d. Sphygmographic curve during increase of pressure is above that obtained in normal air. During this phase there is increase in the total pressure of the blood.

33d. Diminution in calibre of the vessels of conjunctiva, retina, and in the ear of rabbits; decolorization of the pupil and iris in white rabbits. The pallor of the men who work in compressed air proves the repulsion of the blood from the surface to the interior organs.

34th. Hence arise diminution in the intraocular pressure, contraction of the pupil, pulsation in the ear and jaw, pallor of tympanic membrane.

35th. Introduction of a manometer into the jugular vein shows that the venous pressure diminishes in compressed air.

36th. Temperature increases in the armpit. If exposure to compressed air be of sufficient duration, temperature in the rectum also increases.

37th. Blood leaving the periphery of the body, many of the internal organs are congested, and, hence, the symptoms connected therewith.

38th. Compression of air causes no direct evil results until it reaches four and a half atmospheres.

39th. In relaxing the compression, if the release is too rapid, serious consequences arise.

40th. Sojourn in compressed air is less dangerous than return to ordinary air. This produces congestions, hemorrhages, pains, and derangements of the circulatory system. The evolution of gas in this system can even bring on sudden arrest of circulation and death.

41st. The only way to treat these accidents is by an instant return to compressed air.

In 28th, 29th, 33d, 34th, 37th, Vivenot confounds results with theory of effects of pressures; with the exception of the error thereby introduced, the summary gives an excellent review of the effects of moderate pressure.

To this list of symptoms M. Bert adds the following statements: With air under pressures less than five atmospheres, the oxyhæmoglobin is never completely saturated with oxygen, though it becomes richer therein as the pressure surpasses the normal. These moderate pressures especially interest the phy-

sician and the hygienist, since they are employed in therapeutics and in various industries.

What appears to be most interesting is the determination of the tension at which the maximum of intra-organic oxidation is attained. Direct determinations of the oxygen absorbed, of the carbonic acid and urea excreted in a given time, show that it is in the vicinity of three atmospheres or a tension of about sixty of oxygen. Indirect researches on the rapidity of putrefaction give the same result.

In the higher animals organic oxidations augment in intensity as the point of saturation of oxyhæmoglobin is reached. Observations on inferior creatures, as tadpoles and larvæ, kept for some time under oxygen tensions between twenty-one and one hundred, show that though there may be improved rate in nutrition, there is a departure from the normal character or condition of the part. Germination of seeds is never better accomplished than under the normal pressure and tension of the air, or in a similar mixture of oxygen and hydrogen.

Though the number of pulsations is diminished, and the maximum lung capacity is increased, yet the volume of air which traverses the lungs in a given time does not change sensibly in compressed air.

The greatest lung capacity is produced by the mechanical compression to which the intestinal gases are submitted. Arterial pressure is augmented.

The mechanical effects of pressure on intestinal gas diminish as the pressures increase, following the law of Mariotte. Passing from one to two atmospheres, the diminution is one-half; to four, to one-quarter; and so on.

Though Vivenot's theory of the action of compressed air in producing pallor is hardly tenable, yet it is not the less true that the blood is driven from the periphery to the central organs. From this arise important modifications in circulation and in the nutrition of different parts of the body; modifications from which therapeutics have been able to draw profit.

In closing this article, we are constrained to mention Bouchard's ingenious explanation of the pallor arising in compressed air. He attributes it to compression of the intestinal gas, the elasticity of the abdominal walls exerting a suction action in consequence thereof.

313. Action of Oxygen Under High Tension.—The discovery of the pernicious action of oxygen under high tension is very interesting. Experiments on vegetables and animals, on air-breathing and water-breathing creatures of simple or of compound structures, have shown in the most satisfactory manner

that if oxygen departs in its tension to any great extent from that which it has in air, death rapidly supervenes.

Convulsions come on in hot-blooded animals quickly in air at twenty atmospheres of pressure; with great rapidity at twenty-five atmospheres; but evil effects are produced at as moderate pressures as six atmospheres. As is shown in Fig. 91, the

Fig. 91.

Dog poisoned by oxygen.

rigidity arising from the convulsions is so great that the animal, when held by one foot, stands out as stiff as though it was made of wood.

243. Oxygen Poisoning.—1st. Oxygen acts as a poison when the quantity in the blood reaches thirty-five volumes in one hundred, the normal being fifteen to twenty.

2d. The poisoning is characterized by convulsions which resemble those of tetanus and epilepsy, also those produced by strychnine and phenic acid.

3d. These convulsions are quieted by chloroform, and are caused by an exaggeration of the excitor motor power of the spinal cord.

4th. They are accompanied by more or less diminution in internal temperature. Regarding this, M. Bert says: "When I for the first time saw a sparrow under the influence of condensed oxygen and suffering violent convulsions, I thought that the intra-organic oxidations must produce exaggeration in the temperature. Imagine my surprise when the thermometer showed exactly the opposite result."

Microscopic germs which produce various fermentations die when they are submitted to the action of compressed oxygen; putrefaction is arrested.

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... being represented by its percentage mul-...ure, death supervenes:

... tension of carbonic acid rises to 26 (whether ... pressure be above or below the normal). In this ... tures respired must be surcharged with oxygen. ... and applies to other poisonous gases—*e. g.*, carbon mon-... sulphuretted hydrogen.

... When the tension of oxygen reaches 300 (independent ... any special percentage and pressure). In the case of pure oxygen it is when the pressure becomes 3 atmospheres. An animal respiring air in which the percentage of oxygen is steadily increasing, and another respiring air in which the pressure is steadily increasing, both show the same symptoms. In pure oxygen a pressure of 3 or 4 atmospheres, in the air a pressure of 20 atmospheres, bring on oxygen poisoning.

246. Therapeutical Effect of Respiring Oxygen.—From the time of Priestley many have advocated the respiration of vital air or oxygen, and it was for a time employed; but having fallen into disuse, it has only recently been brought forward again as a therapeutical agent.

As ordinarily prescribed for patients, it is given nearly pure. The maximum quantity administered in France is 30 litres, which are consumed in from five to seven minutes. This method labors under two objections: 1st. We cannot expect that any permanent relief is to be obtained by a slight increase of the oxygen in the blood during ten minutes or so. 2d. As the oxygen is pure, it is quite possible that a sufficient quantity may be administered to over-pass that best calculated for the maximum of intra-organic oxidations. So shock may be produced, which acts in the opposite manner to that intended.

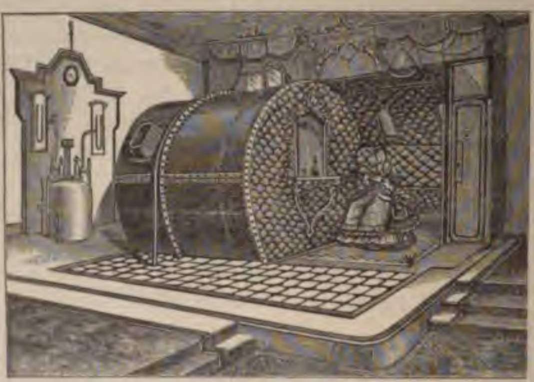
It is to be hoped that hereafter pure oxygen will only be given in alarming cases of asphyxia, as in poisoning by carbonic oxide or by sewer gas, where there is but little time to act. The proper method is to employ an air containing about 60 per cent. of oxygen, and to continue the inhalation for an hour.

In the treatment of a chronic affection like anæmia, the better way is for the patient to respire an air containing about 25 or 30 per cent. of oxygen, for a couple of hours every day. For this time, there would be required about a cubic metre of the mixture.

247. Therapeutical Uses of Compressed Air.—Our knowledge of the use of compressed air as a therapeutical agent is largely due

to Junod, of Paris; Tabarié, of Montpellier; and Pravaz, of Lyons. As the value is better appreciated every day, it will doubtless before long be more generally employed. More than twenty establishments are now in operation in various European cities. Managers of these employ different degrees of compression, varying from 10 to 30 centimetres of mercury. They report excellent results in the treatment of *emphysematous asthma; chronic bronchitis; chloro-anæmia; passive hemorrhages.* It is both tonic and sedative in its effects.

FIG. 92.



Aero-therapeutical establishment at Milan.

In *asthma* moderately compressed air acts beneficially, chiefly for mechanical reasons. In *anæmia*, on the contrary, its favorable action is owing to the better saturation of the oxyhæmoglobin with oxygen. This is evident from the fact that in the latter case equal advantages may be obtained by the respiration of air containing a greater percentage of oxygen. In asthma, though the increase in per cent. of oxygen improves the condition of the patient, the amelioration is small compared with that obtained by breathing the compressed air of compression cylinders.

There has been thus far too much timidity in the therapeutic use of compressed air. In the medical apparatus the extreme pressure has hardly ever reached two atmospheres. It might be pushed without inconvenience to three atmospheres—to the point, in fact, of maximum of intraorganic oxidations.

Pravaz has employed compressed air in *surgical operations.* It is surprising that its application for the reduction of *strangulated hernia* has never been attempted where the intestine contains so much gas as to hinder reduction. A pressure of an additional atmosphere would diminish the gas to one-half, which

would certainly be an advantage; and taxis might be commenced in the compression cylinders.

In certain *tympanitic affections* where suffocation is imminent, relief quickly follows a brief sojourn in a compression cylinder. In this case the action is mechanical.

The employment of pressures beyond three atmospheres for medical purposes is also worthy of trial; under these conditions there is diminution of oxidation. This offers an antiphlogistic remedy the value of which has not yet been determined. Physicians having charge of workmen in the caissons used in bridge building have established the fact that *oxygen at high tension exercises a favorable action on inflammatory phenomena.*

248. Hygienic Management of Compressed Air.—Men in the caissons used in construction of piers of bridges have not yet been submitted to pressures where compression of the air is dangerous. The greatest pressure thus far attained was in the bridge at Saint Louis, where it was nearly four and a half atmospheres. Anæmia has appeared as a consequence of such severe pressure, but the complication of conditions is so great that it is difficult to affirm anything with certainty.

The necessities of engineering may at some future time compel a resort to pressures greater than five atmospheres. The consequences to workmen will then become exceedingly grave. Even a brief exposure to ten atmospheres would often be attended by sudden death.

If the construction of a bridge requires that workmen must be exposed to pressures of more than five atmospheres, and its importance is so great that expense is a minor affair, the result may be accomplished by the *employment of an air containing a smaller percentage of oxygen than normal atmospheric air;* an air so adjusted that under the pressure to be employed the oxygen tension shall be between 21 and 60.

Air of this character may readily be obtained by the apparatus of Tessié du Motay, in which oxygen is prepared by separating it from atmospheric air. Air voided from this machine consists chiefly of nitrogen, most of the oxygen having been removed. By adding to this nitrogen air proper proportions of atmospheric air, mixtures can readily be obtained which would at various pressures provide an atmosphere having an oxygen tension similar to that of normal air. *Hydrogen also might be employed for the dilution of ordinary air.*

In preparing such mixtures, if it is desired to have the oxygen at the same tension as in air, all that is required is to divide the percentage of oxygen in air by the atmospheres of pressure. For ten atmospheres of pressure the mixture would contain two per cent. of oxygen. In practice it would doubtless be better

. . the oxygen tension of ordinary air; . . der these conditions the mixture . . . of oxygen. This under a pressure . . give the tension of 40 required.

. . **mpressed Air.** — Air in caissons or tubes . . . At pressures of three and a half . . . of the bridge at Kehl, M. Bucquoy . . arbonic acid gas. In this case work- . . . ch at normal pressures would contain . . ension equal to 8.30, which would be

. . . , but also carbon monoxide arises from . . ons attending the use of artificial lights. . . . necessary in mining. Gases emitted . . . are also to be considered; in the com- . . ese doubtless have their noxious power . . e proper remedy for all such possible . . gh ventilation.

. . **compression.**—The difficulties of compression . . . it remains to deal with those of decom- . . from the highly condensed air to that of . .

. . der high pressures a *quantity of nitrogen . . d, and as reduction of pressure takes place, . . . state.* Even with ordinary air in the . . ents have arisen from this cause. It is . . with condensed atmospheres so rich in . . ation would be exceedingly grave, and

. . *. by a gradual relaxation of pressure.* . . ssure does not exceed two atmospheres it . . hough there is rarely immediate danger. . . abituated to a gradual relaxation of pres-

. . hree atmospheres it is best to allow half an . . . on of pressure. Between three and four . . ar should be allowed, and the slowness of . . . a properly arranged stopcock.

. . difficulty arises and a very grave one. *It . . attends the expansion of air.* This must . . clothing, and the presence of steam heaters

. . . for meeting this trouble is the use of two . . . pression both properly warmed, workmen

passing from that of 3 to that of 2 atmospheres remaining about a quarter of an hour in each.

The longer men have been in the tubes the slower should the decompression be, for the tissues having absorbed nitrogen, time must be given for it to pass first into the blood and then into the atmosphere. It is best not to oblige the workmen to work for long terms, and they should only labor one term in a day.

In like manner, divers working about wrecks and in pearl and sponge fisheries, where the depth exceeds 100 feet, should be provided with means to enable them to return gradually to ordinary pressures.

251. Nature and Treatment of Decompression Accidents.—In spite of all precautions accidents occur. Gas may be freed in the vicinity of the heart, in the heart, in the spinal cord. What then is to be done? *Oxygen should be inspired as quickly as possible.* For this purpose a supply should always be at hand compressed in steel gas holders. *The patient should first be submitted without losing a moment to air more compressed than that from which he has come*, so as to insure the return of the free gas to the state of absorption in the tissues. Then the pressure should be relaxed with extreme slowness.

When compression has exceeded four atmospheres it is always prudent to respire oxygen immediately on returning to the atmosphere. Especially should this precaution be taken by divers, even though there is no appearance of trouble.

If *paraplegia appears*, recompression should at once be resorted to with respiration of oxygen; especially when the trouble appears some time after the return to air, should these be promptly used. It is no longer a probability of obstruction in the pulmonary circulation, *but a certainty of the formation of a gas bubble in the vessels of the spinal cord*, and to remove this compression must be resorted to, and thereby enable the blood to reabsorb it.

Workmen in compressed air suffer more or less from sudden expansion of intestinal gases on leaving the caissons. The froth formed in the liquids of the digestive apparatus when pressure is too quickly relieved, occasionally causes indigestion.

252. Relations of Barometric Variations to Natural History.—In closing his investigations on the physiological effects of variations in pressure, M. Bert says:

The effects of diminution of pressure on the geographical distribution of plants and animals, have been demonstrated. The study of nature does not afford any equivalent illustrations of the effects of increased pressure, at least as far as aërial

creatures are concerned. Regions lower than the level of the ocean, like the Caspian and Dead seas, have only slight depression and few inhabitants. We should expect the case to be very different with creatures which live at depths of 4000 or 5000 metres in the ocean.

The Bathybius, which has played so important a part in modern theories of nature, and which some think belongs to the mineral kingdom, does not appear to suffer any mechanical inconvenience from the enormous pressure to which it is constantly submitted, and with which its parts are in equilibrium. It would be entirely different if a creature accustomed to live at 2000 metres was suddenly translated to a depth of 4000 metres. The increase of pressure would produce a diminution in the volume of its body which could scarcely happen without injurious consequences. In like manner, a creature transferred from 4000 to 2000 metres of depth, would undergo a dilatation that would have evil consequences. It is this dilatation that in all probability causes the death of so many creatures brought from great depths in dredging operations.

Compression and relaxation of pressure produce profound mechanical effects upon water creatures which have closed swimming bladders. In this case, as M. Moreau has shown, any sudden variation of pressure, by its action on their swimming bladder by diminishing its volume, can so modify their mean density as to carry them many metres above or below the zone in which they ordinarily find their habitat. Sudden exhaustion forces them to the surface, the swimming bladder dilating even to bursting. In the other case increase of density causes them to sink indefinitely in the ocean abysses, the bladder ever contracting, and the density of their bodies increasing in the same ratio as that of sea-water. Ordinary variations of barometric pressure are so limited that they do not appear to have any serious influence upon fishes. Indeed, if sufficient time be given, these creatures can increase or diminish the amount of gas in the air-bladder, either secreting oxygen from the blood or absorbing it from the bladder, as occasion requires. They thus adapt their size and density to such moderate variations of pressure as ordinarily arise.

When compressed oxygen is forced into water under high pressure, aquatic creatures placed therein die. To produce this effect, the gas must be compressed independently of any pressure the column of water may bring to bear upon it. Whatever the depth of the column of sea-water may be, it cannot increase the proportion of dissolved oxygen. This fact has been established beyond a doubt by analyses of samples of water taken at great depths. Indeed, there is, according to the analyses of Lant

Carpenter, a less percentage of oxygen in sea-water taken from great depths than in that at the surface.

Sea-water contains an average of 2.8 volumes of gas to 100 of water. This gas has the following composition:

	At surface.	At great depth.
Oxygen	25.00	19 53
Nitrogen	54.21	52.60
Carbonic acid gas	20.84	27.87

Showing diminution both in oxygen and in nitrogen; from this two consequences ensue: 1st. A sojourn at great depths does not bring peril from increase of tension of the dissolved oxygen. 2d. Rapid relaxation of pressure does not produce evil effects, since there is no excess of nitrogen dissolved in the fluids or tissues. Free gas is never found in the tissues of a creature brought from great depths.

It is a very different matter if there is a sudden influx of condensed gas at the bottom of a sea, even at the moderate depth of one hundred metres. Then the conditions for production of increased tension of the dissolved gas exist, and every moving creature that comes within its reach is destroyed. It was doubtless owing to this cause that in the month of March, 1882, such extensive areas of the North Atlantic were covered with dead fish.

If we consider the role which oxygen has played in past geological ages, we cannot fail to perceive that barometric pressure has acted a most important part in modifying the character of life on the surface of the globe.

In the first ages of our planet the tension of oxygen in the atmosphere must have been much greater than at present, and for two reasons: 1st. The thickness of the atmosphere was greater. 2d. The percentage of oxygen also was greater, since the rocks were not yet cool, nor had they, in many cases, reached their maximum of oxidation. At each successive epoch the atmosphere penetrated deeper and deeper into the soil, and the mass of oxygen diminished in proportion. We may, therefore, says M. Bert, imagine that there was a time when living creatures could not exist on the earth on account of the great tension of the oxygen of its atmosphere, and that finally the time arrived when, by reduction of its tension, their existence became a possibility.

There are, he adds, three conditions which practically control the existence of life. They are temperature, tension of oxygen, and of carbonic anhydride. Creatures which resist the greatest extremes of this triumvirate belong to the group of vibrios. It was probably in them that life made its advent, and in them it will make its exit from our planet.

253. Bert's Résumé of His Results.—To put the subject of physiological action of variations in tension of oxygen in as clear and concise a form as possible, Bert gives a résumé of his work, of which the following is a condensation:

a. Diminution of barometric pressure acts on living creatures by decreasing the tension of oxygen in the air they respire and in their blood (anoxyhémie of Jourdanet), and thus menacing them with asphyxia.

b. Augmentation of barometric pressure acts by increasing the tension of the oxygen in air and in blood.

Up to about three atmospheres, increase of tension produces greater activity in intra-organic oxidations.

Beyond five atmospheres the intensity of oxidation diminishes, it changes in its character, and at last with sufficient increase of pressure ceases altogether.

Consequently all living things, aërial or aquatic, animal or vegetable, complex or single celled; all anatomical elements, whether isolated (as blood corpuscles), or grouped in tissues, perish, with greater or less rapidity, when placed in air sufficiently compressed. The only exceptions to this law are the reproductive corpuscles of certain microscopic creatures. In higher animals death is preceded by tonic and clonic convulsions of extreme violence.

In vertebrates, sudden accidents produced by great tension in the oxygen do not appear until the hæmoglobin is saturated with oxygen, and this gas is brought in contact with the tissues in a state of simple solution. One can then say that the anatomical elements are anaérobies.

c. The ferment diastase, venomous poisons, and vaccination virus resist the action of compressed oxygen.

d. The evil effects of diminution in atmospheric pressure are effectually prevented by the respiration of an air sufficiently rich in oxygen to maintain this gas at its normal tension of 20.9.

The effects of increase in pressure can, in like manner, be avoided by a sufficient diminution in the proportion of oxygen to a tension of 20.9.

e. In a general way, respirable and noxious gases (oxygen and carbonic acid, for example) act on living beings according to the tension they possess in the atmosphere containing them. This tension is determined by multiplying their percentage by the barometric pressure. Increase in one of these factors may be compensated by diminution in the other.

f. In animals with closed air-bladders (as ordinary fishes) or those with sacs which only communicate with air when emptying (intestinal canal of aërial vertebrates), and also those with sacs which communicate with air both during compression and

relaxation (lungs of aërial vertebrates), decrease or increase of pressure can only have physico-mechanical effects.

g. Sudden release from pressure of many atmospheres, with few exceptions as in *f*, causes evolution of free nitrogen, which was previously dissolved in the blood and tissues.

h. Wild animals all over the globe are accommodated to the tension of oxygen under which they live. Decrease or increase of pressure from the normal affects them injuriously when they are in health.

Therapeutics might draw a useful lesson from these modifications in pathological conditions.

i. Barometric pressure and percentage of oxygen in air have not always been the same. The tension of this gas has, and without doubt will continue to diminish. That is a factor of which no count has yet been taken in biological speculations. The difference in its powers under different tensions leads to the supposition that the microscopic creatures which were the first to appear will be the last to pass away when life is extinguished from the insufficiency of oxygen for the continuation of its support.

j. The common statement is not true that plant life must have appeared on the globe before animal life, in order to purify it from the great quantity of carbonic acid gas it contained. The fact is that germination, except in the case of a few moulds, cannot take place in air sufficiently charged with carbonic acid gas to be fatal to a hot-blooded animal.

It is not right to explain the priority in appearance of reptiles before hot-blooded animals, on the hypothesis that they can breathe an air richer in carbonic acid gas than animals can. The truth is, reptiles succumb to this gas more readily than either birds or mammals.

SECTION V.

ULTRA-GASEOUS OR RADIANT MATTER.

CHAPTER XVII.

GENERAL AND SPECIAL PROPERTIES OF RADIANT MATTER.

Idea of radiant matter descended from Faraday—Crooke's argument for radiant matter—Crooke's explanation of the kinetic theory of gases—Action of radiometer explained—Extent of mean free path of the molecules in radiant matter—Radiant matter exerts phosgenic action where it strikes—Proceeds in straight lines—Intercepted by solid matter casts a shadow—Radiant matter striking a solid produces change therein—It exerts mechanical action where it strikes—Is deflected by the magnet—Radiant matter produces heat when its motion is arrested—The molecule the true matter—The absolute vacuum tube.

THE following account of ultra-gaseous or radiant matter is an abstract of a lecture given by Professor Crookes before the British Association, on August 22, 1879, and of articles published since that date.

254. dea of Radiant Matter Descended from Faraday.—In a lecture delivered by Faraday, in 1816, we find the first use of the term radiant matter. He says, "if we conceive a change as far beyond vaporization as that is above fluidity, and then take into account also the proportional increased extent of alteration as the changes rise, we shall, perhaps, if we can form any conception at all, not fall far short of that of radiant matter; and as in the last conversion many qualities were lost, so here also many more would disappear."

In 1819, Faraday says, "matter may be classed into four states, solid, liquid, gaseous, and radiant." He adds:

"As we ascend from the solid to the fluid and gaseous states, physical properties diminish in number and variety, each state

losing some of those which belonged to the preceding state. When solids are converted into fluids all the varieties of hardness and softness are necessarily lost. Crystalline and other shapes are destroyed. Opacity and color frequently give way to a colorless transparency, and a great mobility of particles is conferred."

"Passing onward to the gaseous state, still more of the evident characters of bodies are annihilated. The immense differences in their weight almost disappear. The remains of differences in color that were left are lost. Transparency becomes universal, and they are all elastic. They now form but one set of substances, and the varieties of density, hardness, opacity, color, elasticity, and form, which render the number of solids and fluids almost infinite, are now supplied by a few slight variations in weight, and some unimportant shades of color."

"To those, therefore, who admit the radiant form of matter no difficulty exists in the simplicity of the properties it possesses, but rather an argument in their favor. These persons show you a gradual resignation of properties in the matter we can appreciate, as the matter ascends in the scale of forms, and they would be surprised if that effect were to cease at the gaseous state. They point out the greater exertions which nature makes at each step of the change, and think that consistently it ought to be greatest in the passage from the gaseous to the radiant form."

255. Crooke's Argument for Radiant Matter.—"Gases are now considered to be composed of an almost infinite number of small particles or molecules, which are constantly moving in every direction with velocities of all conceivable magnitudes. As these molecules are exceedingly numerous, it follows that no molecule can move far in any direction without coming in contact with some other molecule. But if we exhaust the air or gas contained in a closed vessel, the number of molecules becomes diminished, and the distance through which any one of these can move without coming in contact with another is increased, the length of the mean free path being inversely proportional to the number of molecules present. The further this process is carried, the longer becomes the average distance a molecule can travel before entering into collision; or, in other words, the longer its mean free path. The greater the mean free path, the more the physical properties of the gas or air are modified. Thus, at a certain point the phenomena of the radiometer become possible. On pushing the rarefaction still further—*i. e.*, decreasing the number of molecules in a given space, and lengthening their mean free path, new and extraordinary experimental results are obtainable. So distinct are these phenomena

from anything which occurs in air or gas at the ordinary tension that we are led to assume that we are here brought face to face with matter in a fourth state or condition, a condition as far removed from the state of gas as gas is from liquid."

"There is one particular degree of exhaustion more favorable than any other for the development of the properties of radiant matter. Roughly speaking, it may be put at the millionth of an atmosphere. At this degree of exhaustion the phosphorescent effects are very strong, and after that they diminish until at last the spark refuses any longer to pass."

256. Crooke's Explanation of the Kinetic Theory of Gases.—In dealing with this and with the properties of radiant matter we quote largely from Prof. Crookes's own words. He says, it is not easy to make clear the kinetic theory, but we will try to simplify it in this way: Imagine that we have in a large box a swarm of bees, each bee independent of its fellow, flying about in all manner of directions and with very different velocities. The bees are so crowded that they can only fly a very short distance without coming into contact with one another or with the sides of the box. As they are constantly in collision, so they rebound from each other with altered velocities and in different directions, and when these collisions take place against the sides of the box pressure is produced. If we take some of the bees out of the box, the distance which each individual bee will be able to fly before it comes into contact with its neighbor will be greater than when the box was full of bees; and if we remove a great many of the bees we increase to a considerable extent the average distance that each can fly without a collision This distance we will call the bees' *mean free path.* When the bees are numerous the mean free path is very short; when the bees are few the mean free path will be longer, the length being inversely proportional to the number of bees present. Imagine a loose diaphragm introduced in the centre of the box so as to divide the number of bees equally. The same number of bees being on each side, the impacts on the diaphragm will be equal, and the mean speed of the bees being the same, the pressure will be identical on each side of the diaphragm and it will not move.

Let us warm one side of this division so as to make it communicate extra energy to a bee when it touches it. As before, a bee will strike the diaphragm with its normal mean velocity, but will be driven back with extra velocity, the reaction producing a pressure on the diaphragm. It will be found, however, that although the diaphragm is free to move, the extra strength of the recoil on the warm side does not produce any motion. This at first sight seems contrary to the law of action and reac-

tion being equal. The explanation is not difficult to understand. The bees which fly away from the diaphragm have drawn energy from it, and, therefore, move quicker than those which are coming towards it; they beat back the crowd to a greater distance, and keep a greater number from striking the diaphragm. Near to the heated side of the diaphragm the density is less than the average, while beyond the free path the density is above the average, and this greater crowding extends to all other parts of the box. Thus it happens that the extra energy of the impacts against the warm side of the diaphragm is exactly compensated by the increased number of impacts on the cool side. In spite, therefore, of the increased activity communicated to a portion of the bees, the pressure on the two sides of the diaphragm will remain the same. This represents what occurs when the extent of the box containing the bees is so great compared with the mean free path, that the abrupt change in the velocity of those bees which rebound from the walls of the box produces only an insensible influence on the motions of bees at so great a distance as the diaphragm.

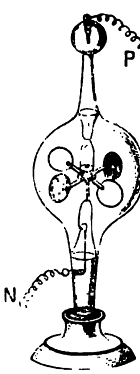
257. Action of Radiometer Explained.—Imagine that we gradually remove bees from the box, still keeping the diaphragm warm on one side. The bees getting fewer, the collisions will become less frequent, and the distance each bee can fly before striking its neighbor will get longer and longer, and the crowding in front of them will grow less and less. The compensation will also diminish, and the warm side of the diaphragm will have a tendency to be beaten back. A point will at last be reached on the warm side when the mean free path of the bees will be long enough to admit of their dashing right across from the diaphragm to the side of the box, without meeting more than a certain number of incoming bees in their flight. In this case the bees will no longer fly quite in the same direction as before. They will now fly less sideways, and more forwards and backwards between the heated face of the diaphragm and the opposed wall of the box. Because of this preponderating motion, and also because they will thereby less effectually keep back bees crowding in from the sides, there will now be a greater proportionate pressure both on the hot face of the diaphragm, and on that part of the box which is in front of it. Hence the pressure on the hot side will now exceed that on the cool side of the diaphragm, which will consequently have a backward movement communicated to it.

We may diminish the size of the bees as much as we like, and by correspondingly increasing their number the mean free path will remain the same. Instead of bees let us call them molecules, and instead of having a few hundreds or thousands let us

have billions or trillions; and if we also diminish the mean free path to a considerable extent we get a rough outline of the kinetic theory of gases.

The explanation of the movement of the radiometer is this. The interior of the glass vessel being highly vacuous, the light or the total bundle of rays included in the term light, falling upon the blackened side of the vanes, becomes absorbed, and thereby raises the temperature of the black side; this causes extra excitement of the air molecules which come in contact with it, and pressure is produced, causing the fly of the radiometer to turn round, the manner in which the motion originates being similar to that described in the latter part of the first paragraph of this article.

FIG 93.

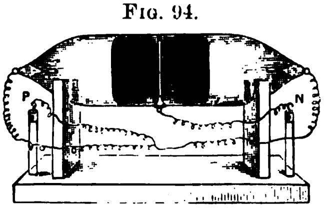


Action of radiometer.

258. Extent of Mean Free Path of Molecules in Radiant Matter.—Regarding this subject Prof. Crookes says: The mean free path of the molecules in air at the ordinary pressure is the ten-thousandth of a millimetre. I have long believed that a well-known appearance in vacuum tubes is closely related to the mean free path of its molecules. If the negative pole is examined while the discharge from an induction coil is passing through an exhausted tube, a dark space is seen to surround it. This dark space increases and diminishes as the vacuum is varied.

For the purpose of illustrating the mean free path, the instrument called the "dark space tube," Fig. 94, has been contrived. It has a pole in the centre formed of a metallic disk, and platinum wire poles at each end. The centre pole is made negative and the terminal poles positive. The induction coil is then set in action. When the pressure is a few millimetres of mercury, a halo of velvety light covers the surface of the pole; as the pressure diminishes, a dark space appears which separates this light from the surface of the metal. When the exhaustion is very good the dark space extends for a couple of inches on each side of the central pole, as is shown in the figure.

FIG. 94.



Dark space tube.

Here we perceive the induction spark actually illuminating the lines of molecular pressure caused by the excitement of the negative pole. The thickness of this dark space—nearly two inches—is the measure of the mean free path between successive

collision of the molecules of the residual gas. The extra velocity with which the negatively electrified molecules rebound from the excited pole, keeps back the more slowly moving molecules which are advancing towards that pole. The conflict occurs at the boundary of the dark space, where the luminous margin bears witness to the energy of the discharge.

The manner in which the dark space forms may be imitated by the following experiment: Let a stream of water fall from a fine jet on the centre of a horizontal sheet of glass. The water spreads over the plate and forms a thin film. The jet of water in the centre, from the velocity of its fall, drives the film of water before it on all sides, raising it into a ring-shaped heap. As the force of the jet is increased, the ring expands in diameter, the effect being analogous to a greater exhaustion in the tubes. The extra velocity of the falling particles of water drives the incoming water before them, and raises a ridge which exactly represents the luminous halo on the margin of the dark space in the tube.

259. Radiant Matter Exerts Phosgenic Action where it Strikes.—Certain precious stones, as the diamond, ruby, sapphire, possess the power of emitting light when submitted to the action of the electric discharge. Other substances, as corundum, precipitated alumina, Becquerel's luminous sulphides, uranium glass, and English and German glass, also possess this property. In illustration of the power of radiant matter to develop phosphorescence when it is under the influence of electricity, Professor Crookes has devised the apparatus called the "ruby tube."

Fig. 95.

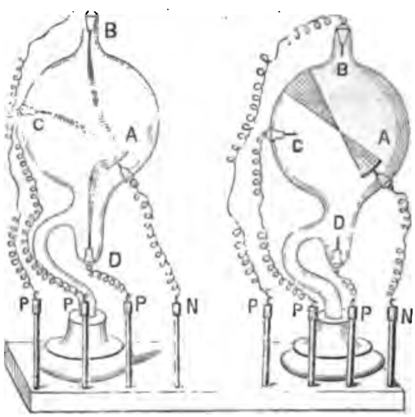
Ruby tube.

It is of the form represented in Fig. 95. In the lower part some chemically pure precipitated alumina, or other phosphorescent substance, is placed. The terminals of the coil look down upon this material, and the tube is exhausted to about one-millionth of an atmosphere.

The moment the coil is put in action, the alumina glows with a bright red light. Other specimens of alumina, on the contrary, emit a green light. Diamonds are found to give brilliant colors of various hues—blue, apricot, red, yellowish, green, orange, and dark green. The glass of which the apparatus for illustrating the properties of radiant matter is made, emits a different color according to its composition. Uranium glass gives a dark green color; English glass, a blue; and the soft German glass, of which most of the instruments are made, a bright apple-green color.

260. Radiant Matter Proceeds in Straight Lines.—In the ordinary phenomena exhibited by vacuum tubes, it is customary, for the more striking illustration of their contrasts of color, to have the tubes bent into very elaborate designs. The positive luminosity caused by the phosphorescence of the residual gas follows all the convolutions and designs into which the glass is twisted. The negative pole being at one end, the positive at the other, the luminous phenomena seem to depend more on the positive than on the negative pole at exhaustions such as have hitherto given the best phenomena of vacuum tubes. The two bulbs, Fig. 96, are alike in shape and position of poles, the only

FIG. 96.



Course of radiant matter.

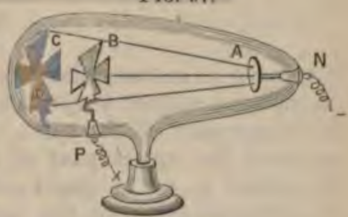
difference being that one is at an exhaustion equal to a few millimetres of mercury—such a moderate exhaustion as will give stratifications or the ordinary luminous phenomena—whilst the other is exhausted to about the millionth of an atmosphere. Connect the moderately exhausted bulb with the induction-coil, and, retaining the pole at one side, A, always negative, put the positive wire successively to the other three poles, B C D, with which the bulb is furnished. As the position of the positive pole is changed, the line of violet light joining the two poles changes. In this moderately exhausted bulb, therefore, the electric current always chooses the shortest path between the two poles, and moves about the bulb as we alter the position of the polar wires.

Repeat the same experiment with a tube that is highly exhausted, and as before make the side pole A the negative, the top pole B being positive. Notice how widely different is the appearance

from that shown by the last bulb. The negative pole is in the form of a shallow cup. The bundle of rays from the cup crosses in the centre of the bulb, and thence diverging, falls on the opposite side as a circular patch of green light. Remove the positive wire from the top and connect it with the side pole C. The green patch from the divergent negative focus is still there. Make the lowest pole D positive, the green patch still remains where it was at first, unchanged in position or intensity. If the negative pole points in the direction of the positive all very well, but if the negative pole is entirely in the opposite direction it does not matter; the line of rays is still projected in a straight path from the negative pole.

261. Radiant Matter Intercepted by Solid Matter Casts a Shadow.—The apparatus, Fig. 97, affords additional evidence of the fact that radiant matter moves in straight lines. In the middle of the pear-shaped vessel is a cross, B, of thin sheet aluminium. It is made the positive pole. The negative pole is at A. In putting the coil in action the rays from the negative pole pass along the tube, and falling upon the broad end C produce phosphorescence. In this phosphorescence a shadow, D, of the cross appears, proving not only that the radiant matter has moved in straight lines from which it does not depart, but also that it is not a mere electrical action, for this would cease at the metallic surface which is the other pole.

FIG. 97.



Shadow tube.

262. Radiant Matter Striking a Solid Produces Change Therein.—In the preceding experiment the cross produces a dark shadow on a bright background. If the action is continued for some time the brightness of the phosphorescence gradually diminishes and almost disappears. If at this point the cross which is supported on a hinge is thrown out of the path of the radiant matter by a sudden movement, the parts of the glass which have hitherto been protected and dark, instantly flash out in brilliant phosphorescence, and a bright image of the cross appears on a dark background. In its turn this also finally disappears.

These facts demonstrate that the battering of the molecules of the radiant material upon the surface of the glass produces a change therein. The exhaustion in this tube is much more perfect than in the dark space tube; the molecules not only passing throughout its whole length, but striking with such force on the wide end that its temperature rises in consequence.

263. Radiant Matter Exerts Mechanical Action where it Strikes.—To the apparatus represented in Fig. 98, Prof. Crookes has given the name of the railway tube. At either end on the upper part are the terminals of the coil. On a glass tramway a little below the axis of the tube, a delicately balanced wheel is placed. Its axis revolves on the tramway and the spokes of the wheel

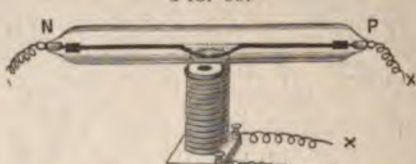
FIG. 98.

Railway tube.

terminate in rectangular vanes. When the coil is put in action the radiant matter projected from the negative pole passes along the upper part of the tube. In its passage it strikes upon the vanes of the upper part of the wheel with so much force that the wheel is set in rapid rotation, and despite the smallness of the circumference of the axis on which it is revolving passes quickly to the terminus of the track. Reversing the poles, the wheel passes in the opposite direction.

264. Radiant Matter is Deflected by the Magnet.—Fig. 99 represents a low vacuum tube, beneath which an electro-magnet has been placed. On passing the induction spark it assumes the form of a narrow line of violet light connecting the two poles

FIG. 99.

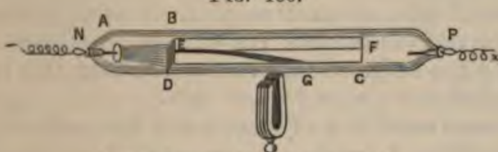


Action of magnet on low vacuum tube.

of the tube. The polar wires of the electro-magnet being then connected with a voltaic battery, the line of light instantly dips down towards the magnet, but quickly rises again and pursues its original course. An essential point in connection with the phenomena produced is that the deflection of the line of light is only momentary. Reversing the current in the electro-magnet, the line of discharge is driven to the upper part of the tube.

Fig. 100, we have a highly exhausted tube with a negative A, at one end, and a long phosphorescent screen, B C, down entre of the tube. In front of the negative pole is a plate ica, B D, with a hole, E, in it. When the current from an tion coil is turned on, a line of phosphorescent light is cted along the screen throughout the whole length of the

FIG. 100.



Action of magnet on high vacuum tube.

n the line E F. On placing a strong magnet beneath the the line of light becomes curved towards G under the etic influence, and waves about like a flexible wand as the et is moved up and down. It is especially to be remarked he deflection is permanent. In the preceding case it was rary. In this case the matter in the tube has assumed a ent condition. Its molecules are projected with great ty and force from one end of the tube to the other; it is t matter. In the former case the molecules are vibrating exceedingly small space, they are much closer together. lectro-current passes along them as along a broken con- r, forming a track of violet light. In the latter case the is the result of the impact or striking of the molecules a phosgenic surface, and is of a different color.

. **Produces Heat When Its Motion is Arrested.**—It has stated that when radiant matter strikes upon glass, and ces green phosphorescence, after a time the glass becomes warm. For ation of the intensity of the heat ced, the adjoining tube was con- . The negative pole, N, terminates cup, A. At the focus of curvature cup, B, there is a small square of sheet platinum. The positive ter- is at P. On putting the coil in ac- he radiant matter is thrown off from egative pole in converging lines, meet at the focus upon the platinum. few moments this becomes red-hot, the coil is of the right kind, and of ent strength, not only sheet platinum, lso the highly infusible iridium-pla- may be forced to melt.

FIG. 101.

Radiant matter produces heat where it strikes.

266. The Molecule the True Matter.—In summing up his wonderful results regarding radiant matter, Prof. Crookes says: "Matter in the fourth state is the ultimate result of gaseous expansion. By great rarefaction the free path of the molecules is made so long that the hits in a given time may be disregarded in comparison to the misses, in which case the average molecule is allowed to obey its own motion or laws without interference; and if the mean free path is compatible with the dimensions of the containing vessel, the properties which constitute gaseity are reduced to a minimum, and the matter then becomes exalted to an *ultra-gaseous state.*

"But the same condition of things will be produced, if by any means we can take a portion of gas, and by some extraneous force infuse order into the apparently disorderly jostling of the molecules in every direction, by coercing them into a methodical rectilinear movement. This we have shown to be the case in the phenomena which cause the movements of the radiometer, and I have rendered such motion visible in my later researches on the negative discharge in vacuum tubes. In the one case the heated lampblack, and in the other the electrically excited negative pole supplies the *force majeure*, which entirely or partially changes into a rectilinear motion the irregular vibration in all directions; and according to the extent to which this onward movement has replaced the irregular motions which constitute the essence of the gaseous condition, to that extent do I consider that the molecules have assumed the condition of radiant matter."

Between the third and fourth states there is no sharp line of demarcation, any more than there is between solid and liquid states, or liquid and gaseous states; they each merge insensibly one into the other.

These considerations lead to another and curious speculation. The molecule—intangible, invisible, and hard to be conceived—is the only *true matter*, and that which we call matter is nothing more than the effect upon our senses of the movements of molecules, or, as John Stuart Mill expresses it, "a permanent possibility of sensation." Space covered by the motion of molecules has no more right to be called matter, than air traversed by a rifle-bullet can be called lead. From this point of view then, matter is but a mode of motion; at the absolute zero of temperature the inter-molecular movement would stop, and although *something* retaining the properties of inertia and weight would remain, *matter* as we know it would cease to exist.

267. Absolute Vacuum Tube.—According to Prof. Crookes, the phosgenic action of radiant matter is best obtained by an exhaustion to one millionth of an atmosphere. Both above and

below this, the action is less intense. Indeed, if exhaustion be pushed as he has succeeded in doing to one twenty-millionth of an atmosphere, the ordinary phenomena of radiant matter disappear.

In illustration of this fact, tubes are prepared in which exhaustion is carried to the extreme of which chemical processes are capable. Tubes so prepared, Prof. Crookes calls *absolute vacuum* tubes. These tubes are less than one inch in diameter, and about four inches in length. Platinum poles pass from their extremities, and terminate about one-eighth of an inch from each other in the interior. On making connection with an induction coil, and throwing it into action, the electricity does not pass between these terminals; but if secondary terminals are placed in the air, the spark will pass between them though they are more than an inch apart.

Though electric manifestations fail to traverse the limited distance between the terminals in these tubes, light traverses the tube in every direction with the same facility. It is, therefore, evident that some form of matter still remains in the tube, though it is not one favorable to electric manifestations. Possibly it may be, or approximate to, that universal form of matter which pervades all space, and to which the name of *ether* has been given (26).

PART II.

ENERGY AND ITS FORMS.

SECTION I.

POTENTIAL ENERGY—ATTRACTION.

CHAPTER I.

ENERGY AND FORCE.

Ideas regarding energy—Potential and kinetic energy—Transformation of energy—Conservation of energy—Degradation of energy—Dissipation of energy—Subdivisions of energy—Ideas regarding force.

268. Ideas Regarding Energy.—Any agent capable of doing work is said to possess energy. The quantity of energy is expressed by the work it can do (296). The most concise description of modern ideas regarding energy is contained in Professor Tait's work on "Recent Advances in Physical Science." I therefore give in this chapter an abstract thereof, in the form of a series of quotations. Concerning the introduction of the idea of energy, Professor Tait says: "It is only within comparatively recent years that it has been generally recognized that there is something else in the physical universe which possesses as high a claim to objective reality as matter possesses, though it is by no means so tangible, and, therefore, the conception of it was much longer in forcing itself upon the human mind. The so-called 'imponderables'—things of old supposed to be matter—such as heat, light, etc., are now known by the purely experimental, and therefore the only safe method, to be but varieties of what we call energy—something which though not matter, has as much claim to recognition on account of its objective existence as any portion of matter. The grand principle of 'conservation of energy,' which asserts that no portion of energy can be put out of existence, and no amount of energy can be brought into existence by any process at our command, is simply a statement of the invariability of the quantity of energy in the universe—a companion statement to that of the invariability of the quantity of matter."

269. Potential and Kinetic Energy.—Professor Tait remarks: "Wherein consists the difference between a mass of snow lying on the mountain side, and the same mass when it has fallen and rests in the valley below? Obviously the two substances are identical, except in so far as molecular changes, such as melting, may have altered the state of some portions of the mass during or after its descent. Yet the elevated mass possesses, in virtue of its elevation alone, a power of doing work or mischief which it has lost entirely when it has descended. By the mere fact then of its elevation, it possesses a power which it does not possess when it has fallen. This is called energy of position, or *potential energy.*"

"But when the snow is detached from the mountain side, in descending it acquires another form of energy, depending entirely on its motion; and thus we distinguish between energy of position and energy of motion, or *kinetic energy.*"

Energy, therefore, is of two kinds: kinetic and potential. A stone falling, a rifle-bullet in its course, a steamship in motion, all possess active actual kinetic energy. A stone on the verge of a precipice, the gunpowder in a rifle, on the other hand, have the power of producing kinetic energy; therefore they afford examples of potential or possible energy. The food we consume, and the air taken into the lungs, in like manner represent so much potential energy, which appears as kinetic energy in the muscular and other actions which result in the body.

In his work on "Solar Physics," Lockyer illustrates the ideas of actual or kinetic and potential or possible energy by an example drawn from social life. "When," he says, "a man pursues his course undaunted by opposition, unappalled by obstacles, he is said to be a very energetic man. By his energy we mean the power which he possesses of overcoming obstacles; and the amount of his energy is measured by the amount of obstacles which he can overcome, by the amount of work which he can do. Such a man may, in truth, be regarded as a social cannon-ball. By means of his energy of character he will scatter the ranks of his opponents and demolish their ramparts. Nevertheless, such a man will sometimes be defeated by an opponent who does not possess a tithe of his personal energy. Now, why is this? The reason is that, although his opponent may be deficient in personal energy, yet he may possess more than an equivalent in the high position which he occupies, and it is simply this position that enables him to combat successfully with a man of much greater personal energy than himself. If two men throw stones at one another, one of whom stands on the top of a house and the other at the bottom, the man at the top of the house has evidently the advantage.

"So in like manner if two men of equal personal energy contend together, the one who has the highest social position has the best chance of succeeding.

"But this high position means energy under another form. It means that at some remote period a vast amount of personal energy was expended in raising the family into this high position. The founder of the family had doubtless greater energy than his fellow-men, and spent it in raising himself and his family into a position of advantage. The personal element may have long since vanished from the family, but it has been transmuted into something else, and it enables the present representative to accomplish a great deal, owing solely to the high position which he has acquired through the efforts of another.

"We thus see that in the social world we have what may be justly called two kinds of energy, namely:

"1. Actual or personal energy.

"2. Energy derived from position.

"Let us now turn to the physical world. In this, as in the social world, it is difficult to ascend. The force of gravity may be compared to that force which keeps a man down in the world.

"If a stone be shot upwards with great velocity, it may be said to have in it a great deal of actual energy, because it has the power of overcoming the obstacle interposed by gravity to its ascent, just as a man of great energy has the power of overcoming obstacles.

"This stone as it continues to mount upwards will do so with a gradually decreasing velocity until at the summit of its flight all the actual energy with which it started has been spent in raising it against the force of gravity to this elevated position. It is now moving with no velocity, and may be supposed to be caught and lodged upon the top of a house.

"Thus it is seen that during the upward flight of the stone its energy of actual motion has gradually become changed into energy of position, and the reverse will take place during its downward flight if we now suppose it dislodged from the top of the house. In this latter case the energy of position with which it begins its downward flight is gradually converted into energy of actual motion, until at last, when it once more reaches the ground, it has the same amount of velocity, and, therefore, of actual energy which it had at first.

"Thus we have also in the physical world two kinds of energy: in the first place we have that of actual motion, and in the next we have that of position."

270. Transformations of Energy.—Of this we have an example in the preceding article. A still better illustration of a multi-

plicity of transformations is afforded by the present method of producing the electric light.

In this the initial act is the combustion or oxidation of coal. This is a *chemical* process by which *heat* is developed. Through the agency of the heat water is volatalized into *steam*, the *elastic force* of which is caused by suitable machinery to produce *motion*. In its turn the motion is converted into a compound development of *magnetism* and *electricity*, and the latter when passed between carbon points produces *light* and heat. Attendant on the motion, and likewise on the passage of the electric arc, *sound* also appears as an accidental result.

Chemical affinity, heat, motion, magnetism, electricity, light, are, therefore, convertible one into another. Indeed, as a glance at the table of the divisions of energy shows, they are virtually mere modifications of the effects of energy. There is, therefore, nothing surprising in the fact of their mutual convertibility or transformation.

An admirable example of the transformation or change of potential into kinetic energy is afforded by the *pendulum in action*. When at rest in its lowest position it may be said not to possess any energy, but when work is done upon it and it is raised to one end of the arc in which it swings, it possesses potential energy by virtue of its position, and can do work. Falling to its lowest position, it accomplishes work represented by its weight multiplied by the vertical height through which its centre of gravity has descended. In the lower part of its course gravity ceases to act, but it now possesses energy by virtue of the velocity it has acquired in its descent. This carries it against gravity to the other extremity of its arc, the kinetic being finally completely transformed into potential energy when it comes to rest and is prepared for a second descent. So the alternate conversion of potential into kinetic energy, and *vice versâ*, continues until all the original energy is transformed in overcoming the friction and resistance of the air to which the pendulum has been submitted during its oscillations.

271. Conservation of Energy.—Again quoting from Prof. Tait, "the velocity of an avalanche of snow constantly increases as it descends, and exact calculation according to physical experiment shows us that the amount of potential energy lost in every stage of the operation is precisely equal to the amount of kinetic energy gained. The process may be inverted if we consider kinetic energy to be originally communicable to a body, suppose, for simplicity, in a vertically upward direction." As in the illustration by Lockyer, "a stone thrown into the air gradually loses velocity as it ascends higher and higher; for an instant, when it has lost all velocity, it pauses and then returns, gradually

gaining velocity as it in turn loses its advantage of position. Calculation applied to this case shows that at every stage whether of the ascent or of the descent, the sum of the potential and the kinetic energies remains precisely the same except in so far as it is modified by resistance of the air. This, however, gives us no exception to the general truth of the principle of conservation of energy, because any energy lost by the stone is communicated without loss of quantity to the surrounding air."

The conclusions arrived at from the experiments of Joule on the mechanical equivalent of heat (766) show that in the passage of energy from one form to another nothing is lost. Energy is as indestructible as matter itself. Its disappearance in one form is only its translation into an absolutely equivalent amount of some other form or forms. The total quantity of matter does not vary, neither does that of energy. To quote from Dr. Arnott:

"There may be an ebb and flow between the relative amounts of the various energies, but the sum of them all is constant and invariable throughout our universe. There may, indeed, be a tendency of all the present energies of nature ultimately to pass into one uniformly diffused heat-quiver; it may be indeed that in some incalculably remote age all the changes will have been rung upon the present distribution of the forms of energy, and that the vitality of all nature will exist merely as a universal pulse. Yet the grand generalization of modern times constrains us to believe that in that pulse will be found the exact representative of every motion and form of energy at present operating around or within us; that, in fact, energy is co-eternal with matter. We cannot say that we know fully the nature of the different energies such as magnetism, heat, electricity, and chemical affinity; but the principle of the Conservation of Energy, with which alone the facts discovered by modern experiment appear reconcilable, justifies us in regarding them all, either as some species of actual motion or as some sort of potential energy inherent in definite arrangements of those minute particles which form the foundation of the material universe."

272. Degradation of Energy.—Returning again to the work of Prof. Tait, he says: "We contemplate, therefore, with reference to energy, its conservation, which merely asserts its objective reality; its transformations, which render it indispensable to the existence of life and the physical changes in the universe; but it has in addition another and even more curious property. We have seen that change is essential to the existence of phenomena such as we observe, and that this change may take place it is necessary that there should be constant transformations of

energy. But some forms of energy are more capable of being transformed than others, and every time that a transformation takes place there is always a tendency to pass, at least in part, from a higher or more easily transformable to a lower or less easily transformable form.

"Thus the energy of the universe is, on the whole, constantly passing from higher to lower forms, and, therefore, the possibility of transformation is becoming smaller and smaller, so that in the lapse of sufficient time all higher forms of energy must have passed from the physical universe, and we can imagine nothing as remaining except those lower forms which are incapable so far as we yet know of any further transformation. The low form to which all transformations with which we are at present acquainted seem inevitably to tend, is that of uniformly diffused heat. We know, in fact, that in order to make any use of heat—to transform it into mechanical power or into any other form of energy—it is absolutely necessary that we should have bodies of different temperatures. We must, as it were, have a source and a condenser. Now, when all the energy of the universe has taken the final form of uniformly diffused heat, it will be obviously impossible to make any use of this heat for further transformation. Thus, so far as we can as yet determine, in the far distant future of the universe the quantities of matter and energy will remain absolutely as they now are; the matter unchanged alike in quantity and quality, but collected together under the influence of its mutual gravitation, so that there remains no potential energy of detached portions of matter; the energy also unchanged in quantity, but entirely transformed in quality to the low form of uniformly diffused heat."

273. Dissipation of Energy.—This is by no means well understood, and many of the results of its legitimate application have been received with doubt, sometimes even with attempted ridicule. Yet it appears to be at the present moment by far the most promising and fertile portion of natural philosophy, having obvious applications of which as yet only a small percentage appear to have been made. Some, indeed, were made before the enunciation of the principle, and have since been recognized as instances of it. Of such we have good examples in Fourier's great work on heat-conduction, in the optical theorem that an image can never be brighter than the object; in Gaus's mode of investigating electrical distribution, and in some of Thomson's theorems as to the energy of an electro-magnetic field.

There can be little question that the principle contains the whole theory of thermo-electricity, of chemical combination, of allotropy, of fluorescence, etc., and perhaps even of matters of a higher order than common physics and chemistry.

Thus also it is possible that in physiology it may ere long lead to results of a different and much higher order of novelty and interest than those yet obtained, valuable though these certainly are.

"It was a grand step in science which showed that just as the consumption of fuel is necessary to the working of a steam-engine or to the steady light of a candle, so the living engine requires food to supply its expenditure in the forms of muscular work and animal heat. Still grander was Rumford's early anticipation that the animal is a more economic engine than any lifeless one we can construct. Even in the explanation of this there is involved a question of very great interest, still unsolved, though Joule and many other philosophers of the highest order have worked at it. Joule has given a suggestion of great value, viz., that the animal resembles an electro-magnetic rather than a heat-engine; but this throws us back again upon our difficulties as to the nature of electricity. Still, even supposing this question fully answered, there remains another—perhaps the highest which the human intellect is capable of directly attacking, for it is simply preposterous to suppose that we shall ever be able to understand scientifically the source of consciousness and volition, not to speak of loftier things—there remains the question of Life. It may be startling to some of you, especially if you have not particularly considered the matter, to hear it surmised that possibly we may by the help of physical principles, especially that of the dissipation of energy, some time attain to a notion of what constitutes life—mere vitality, I repeat, nothing higher. If you think for a moment of the vitality of a plant or a zoöphyte, the remark will not appear so strange after all. Do not fancy that the dissipation of energy to which I refer is at all that of a watch or such like piece of mere human mechanism, dissipating the low and common form of energy of a single coiled spring. It must be such that every little part of the living organism has its own store of energy constantly being dissipated, and as constantly replenished from external sources drawn upon by the whole arrangement in their harmonious working together. Sir W. Thomson's splendid suggestion of vortex-atoms, if it be correct, will enable us thoroughly to understand matter, and mathematically to investigate all its properties. Yet its very basis implies the *absolute necessity* of an intervention of creative power to form or to destroy one atom even of dead matter. The question really stands thus: Is life physical or no? For if it be in any sense, however slight or restricted, physical, it is to that extent a subject for the natural philosopher, and for him alone."

274. Subdivisions of Energy. — The various phenomena exhibited by matter, and which result from the influence of energy

thereupon may therefore, be grouped under two grand divisions: *Potential energy* or attraction, and *kinetic energy* or motion. Each of these may be studied under three phases or conditions. 1st. Molar, or attraction and motion as related to masses of matter; 2d. Molecular, or attractions and motions of molecules; and 3d. Atomic, or the attractions and motions of atoms. Molar attraction and motion belong properly to mechanics; Molecular attractions and motions to physics; Atomic attractions and motions to chemistry. Each of these in its turn presents minor subdivisions, examples of which are given in the following tabular presentation of the subject.

Potential or Energy of Position and Attraction.	Molar.	Mechanics	Gravity.	
	Molecular.	Physics proper.	Cohesion. Adhesion.	
	Atomic.	Chemistry	Affinity, or Chemism.	
Kinetic or Energy of Motion.	Molar.	Mechanics	Direct, or Rectilinear translation.	
			Oscillatory, or Reciprocating.	
			Rotatory	Axial. Eccentric Orbital.
			Centrifugal and Centripetal.	
	Molecular.	Physics proper.	Direct or translation	Capillarity. Diffusion.
			Vibratory Reciprocating Rotatory	Sound. Light. Heat. Electricity and Magnetism, etc.
	Atomic.	Chemistry	Affinity or Chemism	Combination. Decomposition.

Of the above divisions, since atomic attraction and atomic motion belong to chemistry, they are eliminated from the present discussion. Molar attraction and motion we are obliged to examine to a certain extent to enable us to form proper conceptions regarding molecular attractions and motions. Molecular motion presents many phases attended by distinct and characteristic phenomena.

275. Ideas Regarding Force.—According to Newton's first law of motion, *Force is any cause which alters or tends to alter a body's state of rest or of uniform motion in a straight line.*

Matter at rest cannot change its condition of itself; matter in motion cannot of itself change its course from uniform movement in a straight line. This property of matter has been described as inertia (42). Anything which produces motion in a material point or in a mass, or which changes the character or rate of a movement, is a force. Thus gravity, friction,

elasticity of springs and vapors, magnetism, are examples of force.

Momentary forces are those which last but for a brief moment of time, and are called into play by explosions, electric discharges, and impulses of various kinds. *Continuous forces* are those which endure in their action, like gravitation or magnetism. A continuous force which does not vary is called *constant*.

CHAPTER II.

ATTRACTION.

Molar attraction. Gravity—Molecular attraction—Adhesion of solid and solid—Cements—Soldering—Adhesion of solid and liquid—Drops and minims—Solution—Adhesion of solid and gas.

276. Molar Attraction. Gravity.—The fact that two masses of matter exert an attractive influence on each other is shown by the following experiments: A small object, as a bullet, is suspended by a delicate thread, and made to oscillate across the field of a microscope. The thread as it moves to the right and left passes to the same distance on each side of the centre of the field of the instrument, as may be measured by a micrometer. If a large mass, as a cannon-ball, be then brought in the vicinity of the oscillating bullet, and the movements of the thread watched through a microscope, they will no longer be found to be equal in extent on each side of the centre of the field, but will be greater in the direction towards the cannon-ball. The two masses of matter, therefore, exert an attractive action on each other, which is best seen in the case of the smaller body, but is also present in the larger, though it is not so evident on account of its greater size.

That both masses are affected by the attractive force may be shown by placing a globule of mercury on the stage of a projection lantern. The stage of the instrument must be in a horizontal position. By means of a slender knife-blade the globule may be separated into smaller portions. As one of these is gently approached towards another, it will be seen on the screen to move quietly until a certain distance is reached, then the two masses jump, as it were, towards each other and unite, forming a

single globule. In case one globule is greater than the other the motions occur in both, but the larger moves through a less distance than the smaller in proportion as its size is greater.

Masses of matter, therefore, possess a mutual power of attraction—this is inherent to all matter. It is the force by virtue of which the particles of all bodies tend towards each other. It exists between them when at rest and when in motion. It is effective no matter how great or how small the separating space may be, or whether it is occupied by other matter or not.

For the conception of universal attraction we are indebted to Sir Isaac Newton, who determined the law of its action as is expressed in the following terms: "*The attraction between two material particles is directly proportional to the product of their masses, and inversely proportional to the square of their distances.*"

To indicate the attraction of the earth for objects on its surface, the word *gravity* is used.

277. Molecular Attraction is of two kinds, cohesion and adhesion. *Cohesion* is the force which binds together molecules of the same kind. The experimental illustration of this force has been given in (18). Its variation in the different forms of solid, liquid, and gaseous matter, has also been discussed in the study of these varieties of matter.

Adhesion is the force which binds together different kinds of molecules or different masses of matter. It may be considered under three divisions: 1st. Solid and solid. 2d. Solid and liquid. 3d. Solid and gas. By many, cohesion and adhesion are regarded as being essentially the same.

278. Adhesion of Solid and Solid.—Two flat surfaces pressed firmly together will adhere more or less perfectly. Two pieces of glass, the surfaces of which are ground flat and which are called adhesion plates, will adhere when they are pressed together with a sliding motion. That the adhesion is in no way a result of pressure of the air, is shown by the fact that the plates remain adherent though suspended in a vacuum. The more the contact and pressure are prolonged, the firmer is the adhesion. It is by virtue of adhesion of this kind that germs of all varieties become attached to motes in the air, to clothing, and to walls of buildings. *Friction* is, to a certain extent, the product of adhesion.

279. Cements.—Adhesion may be rendered more perfect by the employment of liquid glue and other cements which leave no empty spaces on drying or hardening. In these cases adhesion of the cement is often so strong that fracture occurs more readily in other parts than in those which are cemented. The

r intensity of adhesive over cohesive force is shown by ct that the thinner the layer of cement the stronger its

ients resemble in properties the bodies they unite. are cemented by mortar made of lime and sand, which ck-like in their origin. Organic bodies, as wood, paper, ather, are joined with glue, isinglass, and gum, which are ganic. Metals, with solder made of other metals; the should have a rate of expansion under the influence of itermediate between the expansion rates of the two metals inited (280).

not easy to cement together bodies which are unlike in , as, for example, metal and glass. This is largely owing ferences in their rates of expansion. The only metal can be directly united with glass is platinum. If the im is plated with aluminium the union is more satisfac- since aluminium becomes coated with an oxide which iches glass in its character, and so forms a more per- int.

necessities of surgery often demand that various kinds gical appliances consisting of heterogeneous substances be united. To meet conditions already existing, and to it other appliances that might be devised, the following cements is given.

r of Paris, with or without solution of borax. Roman or hydraulic hardens under water. Mastic cement made of Portland limestone finely mixed with sand and litharge. This is made into a paste with raw or nseed oil, when it is to be used. The surfaces to which it is applied should to secure adherence. 100 of the mixture require 7 of oil. For Portland e fine dust from the sawing of slabs of marble may be substituted.

bove are useful in the making of casts of tumors and malformations arious conditions. Mastic cement is especially useful for various hygienic ions, as cementing the floors of cellars and so preventing ingress of and emanations. It is used in London to cover brick-work.

ous and glutinous cements are very numerous. In the preparation of l and chemical apparatus, the cement usually employed is a mixture of id beeswax, melted together and colored with very fine brick-dust, or et with vermilion, a very little of which goes a long way. The hardness cement may be varied at pleasure during its preparation, by allowing a it to dry on a piece of metal and testing it with the thumb-nail, and add- e beeswax or rosin as is necessary. It is very useful in cementing cork to id in closing the leakage through the pores of cork used in making ap- for experimenting with gases. The layer of cement should be as thin as when it is used to unite surfaces.

of rosin, one of beeswax melted, and a little plaster of Paris added, is ended as a cement for stones and earthenware. The substance must be ugh to melt the cement, and the pieces should be very firmly pressed

d sulphur is used to unite metals and stone.

weller's cement is made of isinglass soaked in water till it swells, this ved in brandy or in rum. In two ounces of this mixture, a little gum m or gum ammoniacum is dissolved by trituration. A piece of mastic the marble is then dissolved in as little alcohol as possible, and mixed with

the preceding at 150° F. The cement is kept in a closely stoppered vial. The vial is immersed in hot water when it is to be used. It resists moisture.

Another cement which resists moisture is made by mixing a solution of isinglass in proof-spirit with a solution of shellac in alcohol.

Common glue melted without water, with half its weight of rosin and a little red ochre added to give it body, also forms a cement which resists water.

Clay and oxide of iron make a cement which hardens under water.

A cement for iron to close cracks and crevices, as in heating furnaces, may be made of 2 parts of sal-ammoniac, 1 of flowers of sulphur, 16 of cast-iron filings. These should be well pounded together in a mortar and kept dry. When used, 1 part should be ground in a mortar with 20 of iron filings, and water added to form a paste of proper consistency to be applied to the joints.

A cement for boilers is made of 6 of clay, 1 of iron filings, and linseed oil sufficient to form a thick paste.

A solution of caoutchouc or India-rubber in a mixture of 100 parts of bisulphide of carbon, and 8 of alcohol, is an excellent cement for leather and similar substances.

One of rubber, four of coal tar, with two of shellac added. When the solution is complete, and the whole heated in an iron vessel, it makes a very strong glue.

Caoutchouc cements are waterproof.

Regarding cements for microscopic preparations, Prof. Carpenter says:

"*Japanner's gold size* is the most trustworthy of all cements for closing-in mounted objects of almost any description. It takes a peculiarly firm hold of glass; and when dry it becomes extremely tough without brittleness. When new it is very liquid and runs rather too freely; it is often advantageous to leave open for a time the bottle containing it until the varnish is somewhat thickened."

"*Asphalt varnish*. This is a black varnish made by dissolving half a drachm of caoutchouc in mineral naphtha, and then adding four ounces of asphaltum, using heat if necessary for its solution. It is very important that the asphaltum should be genuine, and the other materials of the best quality."

"*Black japan*. The varnish sold at color-shops under this name may be used for the same purposes as the preceding. When employed for making 'cement-cells,' the slides to which it has been applied should be exposed to the heat of an oven not raised so high as to cause it to blister; this will increase its adhesion to the glass slide, and will flatten the surface of the rings."

"*Dammar cement*, made by dissolving gum dammar in benzole, and adding about one-third of gold size, has the advantage of drying very quickly; and may be preferably used for a first coat when glycerine is used as the material for mounting."

"*Canada balsam* is so brittle when hardened by time that it cannot be safely used as a cement, except for the special purpose of attaching hard specimens to glass, in order that they may be reduced by grinding."

"*Shellac cement* is made by keeping small pieces of picked shellac in a bottle of rectified spirits, and shaking it from time to time. It cannot be recommended as a substitute for any of the preceding; as when dry and hard it has little hold on glass. But it answers very well for making cells for dry-mounting."

"*Marine glue*, which is composed of shellac, caoutchouc, and naphtha, is distinguished by its extraordinary tenacity, and by its power of resisting solvents of almost every kind. Different qualities of this substance are made for the several purposes to which it is applied; and the one most suitable to the wants of the microscopist is known in commerce as GK4. The special value of this cement, which can only be applied hot, is in attaching to glass slides the glass or metal rings, which thus form 'cells' for the reception of objects to be mounted in fluid; no other cement being comparable to it either for tenacity or durability."

"For attaching labels and covering papers to slides either of glass or wood, and for fixing down small objects, nothing is preferable to a rather thick mucilage of gum arabic to which enough glycerine has been added to prevent it from

drying hard, with a few drops of some essential oil to prevent the development of mould. The following formula has also been recommended: Dissolve 2 oz. of gum arabic in 2 oz. of water, and then add $\frac{1}{4}$ of an oz. of soaked gelatine (for the solution of which the action of heat will be required), 30 drops of glycerine, and a lump of camphor."

280. Soldering.—To unite metals, solders formed of tin and lead are commonly employed. Of these there are three, viz.: *fine solder*, 2 parts tin, 1 part lead; *common solder*, equal parts of each metal; and *coarse solder*, 2 parts lead, and 1 part tin. These in each case are fused together, and cast into bars. The surfaces to be united should be clean and bright. To prevent formation of oxide, which would injure a perfect union of the surfaces, pulverized rosin is dusted over the objects to be united; on the application of heat either by the hot bolt or blowpipe flame, the rosin melts and prevents action of the oxygen of the air upon the metals.

Many metals, as copper, must be tinned before they can be united by soldering. To accomplish this, the surface is first scraped or filed clean, it is then heated, and a little chloride of zinc solution or a little powdered sal-ammoniac dusted on. It is then touched with the rod of tin. If sufficiently heated, it is instantly coated with tin. The excess of tin is wiped off, and the metallic surfaces united under a suitable temperature, more tin or solder being used if necessary.

Silver solder contains 66 per cent. of silver with zinc and copper. The practical application of soldering arises continually in electrical experimentation.

281. Adhesion of Solid and Liquid.—Of this the following experiment is an example. A glass plate is suspended by threads so that its surfaces are horizontal, it is then lowered on a clean surface of mercury, which has been poured into a shallow dish or plate. The moment the glass and mercury come in contact, they adhere with such firmness that considerable force is required for their separation.

This form of adhesion is stronger than that between solids. If oil or water be placed between the adhesion plates (278), they adhere much more firmly than without it. In the case of lowering a suspended glass plate on the surface of water (18), adhesion of the fluid for the solid is greater than cohesion of the molecules of the fluid for each other. This is demonstrated by the fact that when the plates are separated, both surfaces are uniformly coated with liquid. The force which has torn the molecules of liquid asunder, has been inadequate to separate the molecules of liquid from those of the solid.

The same solid may show different powers of adhesion, or wetting power for different fluids. A drop of alcohol falling

[illegible] a film of water, will leave the [illegible] the surface of the glass by [illegible] adhering power. On the other [illegible] little or no wetting [illegible]

[illegible] power or adhesion that causes [illegible] curved surfaces in glass [illegible] varies, the other with it [illegible]

[illegible] has an important influence on [illegible] its true adherent power, [illegible] Photographers are well [illegible] devices to obtain the [illegible] endeavor to secure the [illegible] to the surface of the glass [illegible]

282. Drops and Minims.—In measurement of liquids for medi[illegible] In the case of the [illegible] the sixtieth part of a [illegible] the quantity is very [illegible]

A [illegible] forces, viz.: gravity, cohesion, [illegible] the size of the drop vary. [illegible] Those which are [illegible] The material of which the [illegible] by influencing the adhe[illegible] In view of the [illegible] medicine, the following table [illegible] various medicines is given. It is taken [illegible] Dispensatory.

	Drops		Drops
Acid, [illegible]	[illegible]	[illegible] assafœtida, of fox-	
Acid, [illegible]	[illegible]	[illegible] of opium	120
Acid, [illegible]	[illegible]	[illegible] ride of iron	132
Acid, [illegible] tric	[illegible]	Vinegar, [illegible]	78
Acid, nitr[illegible]	[illegible]	Vinegar [illegible] m	78
Acid, sulph[illegible]	[illegible]	Vinegar [illegible] pium (black drop)	78
Acid, sulph[illegible], aromati[illegible]	[illegible]	Vinegar [illegible] squill	78
Acid, sulphuric, diluted [illegible]	[illegible]	W[illegible]	45
Alcohol (rectified spirit)	[illegible]	Water [illegible] ammonia (strong)	54
Alcohol, diluted (proof spirit)	120	Water of ammonia (weak)	45
Arsenite of potassa, solution of	57	Wine (Teneriffe)	78
Ether, sulphuric	150	Wine, antimonial	72
Oil of aniseed, of cinnamon, of cloves, of peppermint, of sweet almonds, of olives	120	Wine of colchicum	75
		Wine of opium	78

283. Solution.—When a solid dissolves in a liquid, cohesion of the molecules of the solid is broken by their adhesion for the

molecules of the liquid. The limit of solubility is reached or a saturated solution formed, when the attraction of adhesion and that of cohesion are balanced (339). The act of solution is usually attended by a fall in temperature, produced by conversion of sensible into latent heat. When solution of a solid is attended by chemical action, as the formation of a hydrate, there is a rise of temperature, as in the case of lime.

Anything that reduces the force of cohesion favors that of adhesion. If we desire to dissolve salt or sugar more rapidly, we pulverize them. The solution is accelerated by suspending the solid just below the surface of the liquid. Heat also, by increasing the intermolecular spaces, generally favors solution. To this there are some curious exceptions. A solution of lime, for example, made in cold water, will deposit a moiety of the solid material if raised to the boiling point. A solution of sulphate of soda, made in ice-cold water, deposits hard gritty crystals on being warmed.

The explanation of these phenomena seems to be, that both adhesive and cohesive attractions are diminished by an elevation of temperature. Cohesive force being the most sensitive, generally suffers more than adhesive; in exceptional cases the reverse happens, the adhesion has then suffered the most, and solubility is consequently diminished.

As a rule, solids dissolve in liquids which have similar properties; crystalline bodies in water, metals in mercury, fats in oils, resins in alcohol. This constitutes a leading difference between the molecular adhesion of solution and chemical attraction. In the latter, action is strongest between atoms or molecules which are unlike in their nature. The liquid which takes up the solid is called the *menstruum* or *solvent*.

When two or more salts are dissolved in water without chemical action on each other, three conditions result: 1st. The quantity of each salt held in solution is *less* than when it alone is present, though the combined quantity is greater than when only one salt is used. 2d. The quantity of each is as *great* as when only one is used, then the total quantity dissolved is the sum of that taken up in each single solution. 3d. The quantity dissolved is *greater* than when one alone is used; the addition of the second salt in this case increasing the solubility of the first, and often the first increasing also the solubility of the second. See (339).

284. Adhesion of Solid and Gas.—When a sheet of glass is immersed in water, bubbles of gas appear on its surface. In this case the bubbles have arisen from the layer of air which covered the surface of the plate, and was carried down by it when it was immersed in the fluid. The bubbles of air which

soon appear on the inner surface of a goblet of freshly drawn cool water, also afford an example of the adherence of gas to solid surfaces.

In certain cases the adherence of gas to a solid is very great, and requires resort to various devices to overcome it. An example of this is offered in the preparation of a mercurial barometer, in which it is necessary to raise the temperature of the mercury nearly to boiling point in order to expel the film and bubbles of air which adhere to the surface of the glass tube.

When gases are evolved by electrolysis on the surfaces of plates of metal, the layer of gas which adheres to the plate has such increased density that it can cause chemical actions of which it is incapable in the free state. Gases in this condition are called *nascent*. See (335, 336).

The employment of bodies in the nascent state or condition has proved of the utmost service in organic chemistry. It may be said that the great advances in this branch of science are largely due to the utilization of the property in question.

SECTION II.

KINETIC ENERGY—MOTION.

CHAPTER III.

GENERAL PHENOMENA OF MOTION.

Motion and repose—Velocity—Trajectory and law of movement—Kinds of movement—Newton's three laws of motion.

285. Motion and Repose.—A body is in movement in relation to another, when the relative positions of these bodies or of their parts change in any manner whatsoever.

A body is in repose in relation to another, when the relative positions of these bodies or of their parts are fixed or invariable. Further expression of these ideas will be found in (41), on mobility.

In the true or abstract idea of motion, independent of its causes, the *form* of the body is considered without regard to its other properties, whatever they may be. We, therefore, speak of the motion of a point, a line, a surface, a volume, and not of a material body. The body or figure, the motion of which is studied, is called the *mobile*.

In modern physics the study of motion in all its forms and peculiarities is of the utmost importance. It would almost seem that Aristotle was moved by the spirit of prophecy when he gave utterance to the aphorism "He who is ignorant of motion is necessarily ignorant of all natural things."

286. Velocity is the product of space and time: it represents the rate of movement. *In English works when not otherwise stated, the distance is understood to be measured in feet, and the time to be one second.* So a velocity of 10 signifies 10 feet per second. The rate is also understood to be uniform unless otherwise stated. When the velocity is very great, as in the movement of electricity,

it is given in miles per second. The following are examples of velocities. Knowledge regarding them is frequently of use in medico-legal inquiries.

	Miles in one second.
Electricity, short circuits	not less than 200,000
Light	192.500
Electric currents in telegraph wires (voltaic)	12,000

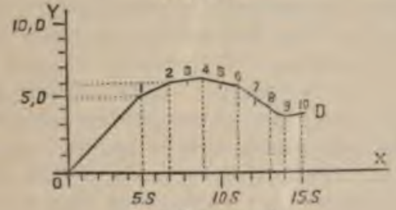
	Feet in one second.
Relative motion of the sun in space	205,920
Aërolites or shooting stars	114,000
Mean rate of the earth's centre in its orbit round the sun	101,061
Sound traversing solid bodies	11,2[illegible]0
Mean velocity of air from explosion of gunpowder	5,0[illegible]
Sound traversing water	4,4[illegible]0
Volcanic stones projected from the volcano of Teneriffe, 1798	3,0[illegible]
A 24-pound cannon ball (maximum)	2,4[illegible]0
Rifle-ball (maximum)	1,6[illegible]
A point at the surface of the earth under the equator	1,5[illegible]5
A common musket-ball (maximum)	1,28[illegible]0
Air rushing into a vacuum	1,2[illegible]0
Volcanic stones projected from Etna	1,2[illegible]0
Sound traversing air at a temperature of 60°	about 1,1[illegible]0
Sound traversing air at 32°	1,09[illegible]
A point at the earth's surface, latitude of London	95[illegible]
Bullet discharged from air-gun (pressure equal to 1500 pounds on the square inch)	69[illegible]
Maximum velocity of wave of Lisbon earthquake, 1755	64[illegible]
Flight of a swift	25[illegible]
Minimum velocity of wave of Lisbon earthquake, 1755	18[illegible]
The most violent hurricane	146 to 160
Flight of a swallow	134
Flight of an eider duck	132
Waves in a heavy swell of the open South Atlantic Ocean	130
Flight of carrier pigeon	120
A hurricane	117
Current in nerve in man	108
Locomotive (70 miles an hour)	102
Flight of a Falcon	83
Race horse	80
A storm (also a tidal wave in the British channel)	73
Ordinary race horse	42 to 50
Flight of a crow	37
A brisk wind	36
Steamship (18 miles per hour)	25
Man on a bicycle	24
Current of most rapid rivers	13
A wind of mean intensity	10
A carriage going six miles an hour	nearly 9
The gulf-stream (maximum)	7
Man walking	6
An ordinary wind	6
Mean velocity of the current of rivers	4
Rate of arterial flow in dog — carotid	1.6 to 0.75
Rate of arterial flow in dog — metatarsal	0.075
Rate of venous flow in dog — jugular	0.75
Rate of venous flow in dog — metatarsal	0. very slight
Snail	0.005

287. Trajectory and Law of Movement.—A point in movement describes a line which is either straight or curved. This line is called its path or trajectory. The trajectory is, therefore, the successive positions of a point in motion (293).

The relation existing between any portions of the trajectory and the rate of movement, or time occupied by the point in making them, is the law of movement.

The law of movement is expressed by an equation or, according to the graphic method, by a curve constructed in the following manner: Two straight lines, O X and O Y, originate at O and pass therefrom at right-angle to each other. Of these

FIG. 102.



Law of movement.

lines let O Y represent distances in tenths of inches, or any other measure, as expressed by the values 5d, 10d, on the scale, and O X times in seconds, as expressed by 5s, 10s, 15s. To these lines the names *axis of abscissas*, *O X*, and *axis of ordinates*, *O Y*, are given. They are also called *coördinate axes*.

Suppose a mobile point during a time equal to 5s has travelled a distance expressed by 5d. The position of the point is found by drawing a line from 5s parallel to O Y, and another from 5d parallel to O X, the intersection of these lines at 1 will then show the position of the point at the moment indicated.

This position connected with O from which the two measures originated, gives the line of movement, which in the case in question is straight, as is shown by O 1.

The line O X in the figure being the axis of abscissas, O 5s is the *abscissa* of the point 1. The line O Y being the axis of ordinates, the dotted line 5s 1 is the *ordinate* of the point 1.

Suppose that in the additional time 2s, the point has travelled an additional unit of distance, its position will then be at 2, and the direction of the line of movement will be changed as represented.

Following the same method, the positions represented by the intersections or crosses at 3, 4, 5, etc., are established, each expressing the time at which the point has travelled a given distance. These intersections being connected, give the curve of movement, O D.

This method is not absolute unless it gives the character of the movement in the intervals between the recorded times.

The law of movement being known or represented by its curve, we possess solutions of the following questions:

1st. In a given time from the moment of departure, what is the distance from the point of departure?

2d. A mobile point being a certain distance from the point of departure, how long from the time of departure has it taken to reach this position?

All kinds of phenomena may be represented by this method, which offers the great advantage of a direct appeal to the eye. Suppose, for example, we desire to show the solubility of a salt at various temperatures. In that case O Y being the temperatures, and O X the quantities dissolved, the curve O D is the curve of solubility of the salt under examination. Again, let O Y represent the number of respirations, and O X the hours at which the count is taken, beginning at 1. The curve 1, 2, 3, etc., D, is then the curve of respiration for the time. The record of the sphygmograph is another application of the same principle, in which the force in action records its own curve. On the *abscissa* and *ordinate* of this curve the relative force of the heart's action at any moment is seen, both for a single beat and for a number of beats compared together.

288. Kinds of Movement.—The simplest kind of movement is that called *uniform movement*, in which equal spaces are traversed in equal lapses of time. In this case the curve produced by the graphic method is a straight line.

All movements which are not uniform are called variable. These may be *uniformly varied* or not. Of these, again, the simplest is the uniformly varied movement, which is either accelerated or retarded. Of accelerated movement, gravity is an example. Retarded movement is illustrated by the resistance of air. Of *irregularly varied movement*, the curve represented in Fig. 102 is an example, the motion being at one time accelerated and at another retarded, as is shown by flexure of the curve.

289. Newton's Three Laws of Motion.—1st. *A body free from the interference of external matter or force will either remain forever at rest, or will move uniformly in a straight line.*

2d. *Any change in the amount or the direction of a body's motion, must be due to the action of some force impressed on the body in the direction of that change, and is a measure of that impressed force.*

3d. *There is no action or motion in the universe, but at the expense of an equal and opposite concomitant action, or "action and reaction are equal and opposite."*

Place a magnet in the pan of a balance and counterpoise it,

en approach a mass of iron under the pan and by weights easure the force required to overcome the attraction. Reverse arrangement, place the mass of iron in the balance pan, interpoise it and approach the magnet. If care has been en that the relative distances apart of the magnet and iron the same in both experiments, the force of attraction is the e in both cases. It matters not what the relative sizes of magnet and mass of iron may be, for any given combi- ion the attraction of each for the other is the same, or, the ion and reaction are equal.

The approach of two boats freely floating, when a person in e is pulling at a rope attached to the other, the recoil of a e not firmly held, the action of a propeller, are familiar amples of the principle of equality of action and reaction.

CHAPTER IV.

MEASUREMENT AND REPRESENTATION OF ENERGY.

e unit of time—The unit of space—Units of weight and mass—Representation of forces by lines—The parallelogram of forces—Momentum and measure of force—Work and unit of work—Measurement of energy.

THREE elements enter into the measurement of force and ergy. They are time, space, and weight or mass. For each these a definite unit has been devised.

290. The Unit of Time is the second. Under ordinary circum- nces, the second employed is that of *mean solar time*. The e which elapses between two transits of the sun's centre at a en meridian is called an apparent day. Since this interval ries slightly from day to day, its average duration is taken d is called the *mean solar day*. It is divided into 24 hours, ch of these into 60 minutes, and these into 60 seconds each. e second, therefore, is the 86,400th portion of a mean solar y. It is determined in practice by the beat of the seconds ndulum (306).

291. The Unit of Space is triple, according as the measurement 1st. Of length or distance; 2d. Of area or surface; and 3d. volume. The English standard of length is the Imperial

yard, or the distance, at 60° F., between two marks on a metallic rod, which is preserved in the Tower of London. Custom has substituted the *foot* or one-third of the yard as the practical unit. The French standard of length is the *metre;* this is very nearly the ten-millionth of an arc of the earth's surface extending from the pole to the equator. It also is practically fixed by marks on a certain rod.

The length of the seconds pendulum in latitude 45° is 0.9935 metre, which differs from a metre by only 6.5 millimetres. The English and French units bear the following relations to each other.

The yard = 0.914383 metre.
The metre = 1.093633 yard.

The *unit of area* is a square each side of which is the unit of length. The *unit of volume* is a cube each edge of which is the unit of length.

292. Units of Weight and Mass.—Bodies are of equal weight if they counterpoise each other when weighed in vacuo.

The English unit of weight is the pound (avoirdupois). It is a certain platinum weight kept in the Exchequer Office in London. All other weights are multiples or submultiples of this. The practical French standard is the gramme, which is the weight of one cubic centimetre of pure water. The kilogramme, or one thousand grammes, is also used as a unit; it is equal to 2.205 pounds avoirdupois.

The weight of a body varies according to the action of gravity upon it. The *mass* of a body is, on the contrary, invariable, it is the quantity of matter it contains.

Any given substance has the same mass wherever it is placed. On the moon its mass would be the same as on the earth, but since the attraction of the moon is less than that of the earth, its weight on the moon would be proportionally less.

If the weight of a body at any given place is divided by the accelerative force of gravity at that place, the quotient obtained will be the same at all places, since weight varies with the force of gravity. This constant quotient is a valuation of the body for all locations, and, therefore, represents its mass. It is generally expressed by the formula:

$$m = \frac{w}{g}.$$

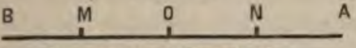
To find the mass of a body for the earth's surface, the value of g at 45° latitude is taken. It is equal to 32.1724.

293. Representation of Forces by Lines.—Both attraction and motion may be represented by means of lines. This method is commonly known as the graphic method. It is invaluable in

enabling us to detect the relations of various phenomena to each other, and to determine the laws under which they are produced. Such lines may be either straight or curved. The following is an example of this method taken from Ganot.

Draw any straight line A B (Fig. 103), and fix on any point O in it. We may suppose a force to act on the point O, along

FIG. 103.



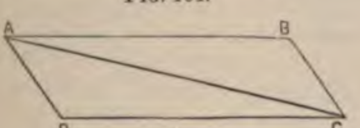
Representation of forces by lines.

the line A B, either towards A or B; then O is called the *point of application* of the force, A B its line of action; if it acts towards A, its *direction* is O A; if toward B, its direction is O B. It is rarely necessary to make the distinction between the line of action and direction of a force, it being very convenient to have the understanding that the statement, a force acts on a point O along the line O A, means that it acts from O to A. Let us suppose the force which acts on O along O A contains P units of force; from O towards A measure O N, containing P units of length; the line O N is said to *represent* the force. The analogy between the line and the force is very complete; the line O N is drawn from O in a given direction O A, and contains a given number of units P, just as the force acts on O in the direction O A, and contains a given number of units P. It is scarcely necessary to add that if an equal force were to act on O in the opposite direction, it would be said to act in the direction O B, and would be represented by O M equal in magnitude to O N.

When we are considering several forces acting along the same line we may indicate their directions by positive and negative signs. Thus the forces mentioned above would be denoted by the symbols $+ P$ and $- P$ respectively.

294. The Parallelogram of Forces is the name given to a device by which we may measure the result of the influences of two forces upon a point, when they both act at the same moment of

FIG. 104.



Parallelogram of forces.

time. The method, as will be readily understood, also covers direction and velocity. It is an application of the principles described in the preceding article.

When two forces act on a point A, Fig. 104, draw from that

point two lines A B and A D, representing the forces in direction and magnitude. On these lines construct the parallelogram A B C D. The resultant of the forces will then be represented in direction and magnitude by the diagonal line A C drawn from the point A. See article (293).

Examples of the application of this and the preceding paragraphs are found in the *chronograph*, for the measurement of small intervals of time; the *myographion*, for the study of the characters of the movements of muscles. To these the *tambour of Marey*, for the transmission of action from one point to another, might be added.

295. Momentum and Measure of Force.—Momentum is the product of the mass and the velocity of a body. A body having a mass equal to five, and moving with a velocity of ten feet per second, is said to have a momentum of fifty.

If a force is constant, it is measured by the momentum it can communicate to a body in a unit of time. If it is variable, it is measured at any moment by the momentum it would give to a body if it continued constant from that instant. The *English unit of force* is, "*that force which acting upon a pound of matter would produce in one second a velocity of one foot per second.*"

In the use of the term, pound-weight, it must be remembered that since gravity differs at different parts of the earth's surface, a pound weight at the equator is not the same as a pound weight at the pole. A weight of platinum which is counterpoised by the elasticity of a spring stretched to a certain point when it is at the equator, requires a different extent of stretching of the spring to balance it at the pole (299).

The question of the momentum or force of winds occasionally becomes a matter of importance in connection with medico-legal inquiries. In this case the momentum is usually estimated as pressure on the square foot.

Momentum of winds.

Miles per hour	Force in pounds on square foot	Character.
5	0.12	Gentle breeze.
10	0.49	A brisk gale.
15	1.11	A brisk gale.
20	1.97	Very brisk.
30	4.43	High wind.
35	6.03	High wind.
40	7.87	Very high winds.
45	9.96	Very high winds.
50	12.30	A storm.
60	16.71	A great storm.
80	31.49	Hurricane.
100	49.20	A hurricane that tears up trees, and destroys all before it.

296. Work and the Unit of Work.—When a force produces acceleration of motion, or when it maintains motion unchanged in opposition to resistance, it is said to do work. Of all standards which might be employed for purposes of measurement, none is more invariable than gravity; even resistance of air varies with its temperature, changes in which cause variations in its weight.

Work does not necessarily include time as one of its factors. The conveyance of 100 bricks to the top of a building requires double the work needed to raise 50 bricks to the same altitude. It is also independent of the origin of the force, whether produced by man, horse, or steam. It is the result only which is dealt with, viz., the elevation of a certain weight to a certain height.

The British unit of work is called the *foot-pound.* It may be defined as the energy required to raise one pound of any kind of matter through the vertical height of one foot at the latitude of London.

The French unit of work is called the *kilogrammetre.* It is the energy required to raise one kilogramme (292) to the vertical height of one metre (291). The kilogrammetre is equivalent to about 7.24 foot-pounds.

To determine the amount of work resulting in any action: *Multiply the whole weight in pounds by the vertical height in feet, and the product is the number of foot-pounds of work done.* For the French system: *Multiply the whole weight in kilogrammes by the vertical height in metres, and the work done is represented by the number of kilogrammetres.*

297. Measurement of Energy.—A railway train going with double velocity possesses double quantity of motion, momentum, or shock-giving power; but its energy or power of overcoming resistance is four-fold that it had at half the speed. It will go four times as far before it stops after the steam is shut off.

A ball which has the power of penetrating one plank when moving with a certain velocity, will penetrate four planks of equal thickness if its velocity is doubled. Hence we have the following rule: *Penetrating power, or energy, increases as the square of the rate at which the velocity increases.*

The *penetrating power of projectiles from firearms* is often a matter of medico-legal inquiry. Of course, it varies for different parts of the body and for different persons according to the thickness of the organs traversed and their composition. In a general way, however, the average resistance of the body is given as being equivalent to about that of two inches of the soft wood called *deal.* At close range, therefore, a bullet

which has sufficient energy to penetrate a number of two inch deal planks, would pass through the bodies of an equal number of individuals.

The relations of work and energy may be better understood by comparison of their units. That of work is the work done in lifting *a one pound weight one foot high.* That of energy is the energy expanded in lifting *a one pound weight one foot high in one second.*

Again, to find the work done, the weight in pounds is multiplied by the height in feet. To find the energy in a moving body, the weight is multiplied by the square of the velocity and the product divided by $64\frac{1}{3}$, or, for rough estimate, 64.

CHAPTER V.

VARIETIES OF MOLAR MOTION.

Rectilinear motion—Falling bodies—Sand-glass—Path of projectiles—Collision—Impact and transmission of impulse—Reflection of rectilinear motion—Oscillating or reciprocating motion—The pendulum—The metronome—The balance wheel—Rotation—Molar motions typical of intramolecular movements—Centrifugal and centripetal forces or motions—Applications of centrifugal force.

MOLAR motion may be: 1st. Straight or rectilinear. 2d. Oscillatory. 3d. Rotatory. 4th. Centrifugal and centripetal.

298. Rectilinear Motion is also called direct, straight, and translatory; the latter term is also used in the case of motion in curved trajectories.

In direct or rectilinear motion the molecules of a body are not disturbed in their relation to each other. The nearest approach to absolute rectilinear motion, as far as the earth is concerned, is offered by falling bodies in which the body is moving in the direct line of gravity or attraction. Movement of a body in any other direction is interfered with by gravity, which tends to draw it out of its straight course. We shall,

therefore, first take up the study of rectilinear motion as presented by falling bodies.

299. **Falling Bodies.**—The ancients maintained that the velocity of a falling body is proportional to its weight, and cited the example of a stone and a feather. When Galileo denied this, he was ridiculed by the disciples of Aristotle, and though he proved his opinion by dropping bodies of different weights from the leaning tower of Pisa, and showing that they all struck the pavement at the same time, they were still incredulous.

The only force with which falling bodies have to contend, is resistance of the air. In the case of very light solids this is so great as to drive them from their rectilinear course, as is shown by the manner in which a feather or a piece of paper falls through the air. Removing this resistance and leaving the body to the simple action of gravity, as may be done in the experiment of the guinea and feather tube (193), we find, that in a vacuum all bodies have the same rate of movement at the same moment of time. The rate of movement or velocity of a falling body can, therefore, only be correctly measured in a vacuum.

In the case of falling liquids it is partly resistance of the air which causes them finally to break into drops, or even into a fine mist, as is seen in the Falls of Montmorency and at the Staubach in Switzerland. In a vacuum liquids fall like solids, without disturbance of their molecules, as is shown by movement of the fluid in the instrument called the water hammer (196).

The space traversed by a body falling in vacuo from a state of rest, is roughly given at sixteen feet at the end of the first second, but it varies at different latitudes as is shown in the following table:

St. Thomas	lat. 0° 25′ N.	it is	16.0478	feet.
New York	" 40° 43′ "	"	16.0797	"
Paris	" 48° 50′ "	"	16.0909	"
Hammerfest	" 70° 40′ "	"	16.1182	"

These differences are owing to variations in the attractive force of gravity at these latitudes. A body near the equator tends to fly off from the surface by centrifugal force (311). By just so much is the force of gravity diminished. At the pole the centrifugal force is nothing. Again, the earth is not a true sphere, but is flattened at its poles. The polar regions, therefore, being nearer to the centre of gravity of the earth than the equatorial, attraction of gravity is greater at the poles than at the equator. It is these causes taken together which increase

the gravity and weight of a body at the pole compared with that it has at the equator, and also increase the distance through which it falls in one second. At the equator the attraction is less by about $\frac{1}{192}$ part of its value at the poles.

The velocity of a falling body at any moment of time has been experimentally proved by various forms of apparatus, among which Atwood's machine and that of Morin are worthy of special mention. In the latter a falling body traces its own curve of movement on a revolving cylinder. The investigations in question demonstrate that the velocity of a falling body is proportional to the time during which the motion has lasted. It increases in an arithmetical ratio or progression. At the end of the first second it is thirty-two feet per second; of the second, sixty-four; of the third, ninety-six; and so on.

In all there are three laws under which the phenomena represented by falling bodies may be grouped, as follows:

1st. *In a vacuum all bodies fall with the same velocity from a state of rest.*

2d. *The distances traversed are proportionate to the squares of the times.*

3d. *The velocities are proportionate to the times.*

300. The Sand-glass.—In former times measurements of brief lapses of time were made by the movement of falling bodies such as water and sand. Where the first of these was used the clock produced was called a *clepsydra*. When sand or other finely divided solid was employed it was called a *sand-glass*.

Fig. 105.

Sand-glass.

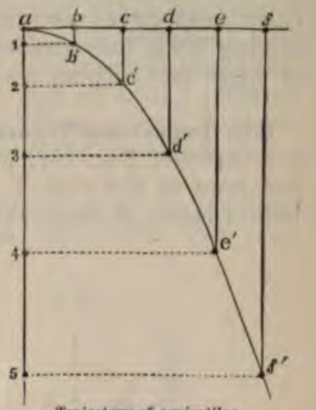
This instrument consists of two hollow glass cones set apex to apex, and communicating with each other by a fine opening at their apices A. The upper division contains such quantity of sand as requires a given lapse of time to fall through the opening into the lower division; according as this is 1, 3, 5, or more minutes, the apparatus is called a 1, 3, or 5 minute sand-glass.

When time is to be measured, all the sand is run into the lower division; at the instant of beginning the measurement the glass is quickly inverted, bringing the filled division uppermost. As the last particle passes through the opening the operator calls *time*. The sand-glass is still employed to measure time in casting the log by sailing vessels.

301. The Trajectory of Projectiles.—If we exclude resistance of the air, the following presentation of this problem would be its solution when a spheroidal projectile is thrown in the horizontal direction.

Let *a*, Fig. 106, be a body thrown with a velocity of *a b* feet per second. If nothing interfered with its motion, it would in 2. 3, 4, 5 seconds reach the points *c*, *d*, *e*, *f*. But during its transit gravity is acting upon it, the vertical positions 2, 3, 4, 5, represent the effect of this force during the time the original projectile force is in operation, consequently the actual course or trajectory of the projectile is the resultant of these two forces. At the end of the first second the projectile is at *b′* instead of *b*; at the next, at *c′*, and so on. Connecting these points we obtain the curved line *a f′*, which is a parabola.

FIG. 106.



Trajectory of projectiles.

If the original line of projection is not horizontal, but forms an angle with the horizon, the theoretical trajectory of the object would still be a parabola, and the greatest range would be attained when the original course was at an angle of 45° with the horizon. In actual practice resistance of the air, elongated form of projectile, and the rotatory motion upon its long axis which is imparted by the rifling of the gun, produce a certain amount of variation from the theoretical course.

302. Collision.—Problems in connection with collision of interest to physicians are of three kinds. 1st. When a moving body strikes another body at rest. 2d. When both bodies are moving in the same direction, the rearmost one having the greater velocity. 3d. When the bodies are moving in opposite directions. In considering these propositions, we may take momentum as the means of comparison, and attribute it in the first case to the action of gravity.

Momentum (295) is the product of the mass or weight of a body, and its velocity. Apply these data to the consideration of phenomena presented by the fall of a man from a scaffolding, estimating his weight at 128 pounds.

Time.	Distance.	Velocity.	Momentum.
1 second.	16 feet	32 feet per second.	4.096
2 "	64 "	64 " " "	8.192
3 "	144 "	96 " " "	12.288
4 "	256 "	128 " " "	16.384

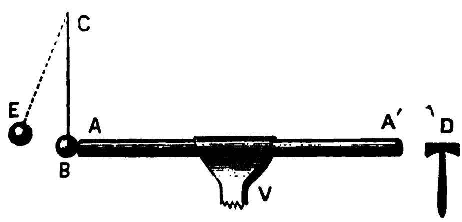
The momentum acquired at the end of each second of fall is sufficient explanation of the terrible consequences of such accidents.

In the second case, where one body overtakes another, the momentum of impact will be the difference of their respective momenta.

In the third case, where they collide with movements in opposite directions, the momentum of impact will be the sum of their respective momenta. Hence the severe consequences arising when two persons running in opposite directions collide, or when two railway trains meet in opposite courses.

303. Impact and Transmission of Impulse.—In the arrangement represented, Fig. 107, a rod of steel, A A′, is firmly fixed in the jaws of the vice V. Against the end of the rod at A, a ball of ivory, B, rests, suspended by a thread from C. On striking

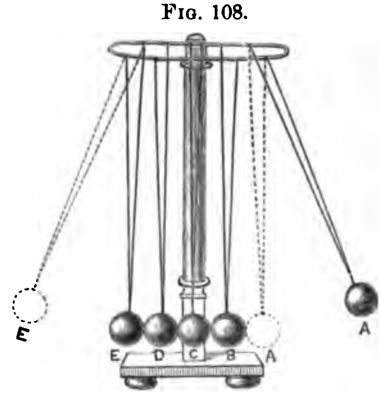
FIG. 107.



Impact and transmission of impulse.

ing the extremity of the rod at A′ with the hammer D, the impulse given by impact of the hammer is transmitted along the rod, and the ball B is thrown off from its opposite extremity, as is shown by the dotted line and the position E.

FIG. 108.



Collision balls.

For investigation of the above, the apparatus, Fig. 108, may be employed. It consists of a series of balls, A, B, C, D, E, made

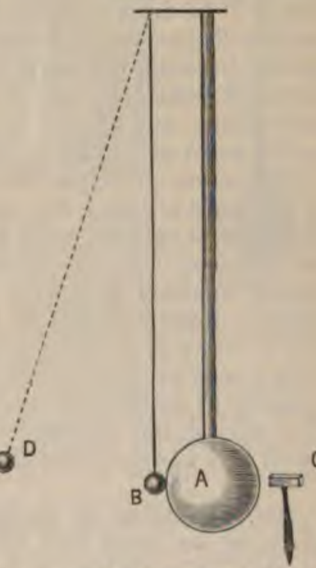
of ivory or other elastic material. These are suspended from a rod, their centres being in the same straight line, and surfaces touching each other.

Raising the first ball into the position A, and allowing it to fall, when it reaches the position indicated by the dotted line at A it strikes against B; thence the impulse is delivered to C and D, without any appreciable motion of either; D finally delivers it to E, which being free to move, flies off to the position of the dotted line at E, the ball E exhibiting almost as much deviation from the perpendicular as was given to A, which delivered the original impulse.

Let us conceive that the balls in the above experiment represent a line of molecules in the steel rod, Fig. 107. We then perceive that when such a rod is struck, the impulse produced by the impact is transmitted from molecule to molecule along the rod in straight lines, and is delivered at its extremity with little or no movement of the intervening molecules from their position.

A motion such as that we have described is sometimes called a *longitudinal* impulse or vibration (365). In this, whatever movement or changes the particles undergo are in the same course as the track of the wave, and not at right angles or transverse to it as in waves on the surface of water.

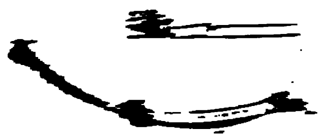
FIG. 109.



Impulse through water.

Fluids as well as solids have the power of transmitting impulse. In Fig. 109, A is an India-rubber bag and tube, filled with water, and suspended from a bar. At B a sphere of cork or other light material touches the surface of the sack of fluid. Tapping with a small mallet C, or with the finger on the opposite side of the bag, the impulse is transmitted through the fluid, and the cork thrown off to the position D.

The above is an experimental illustration of the principle upon which physicians depend in the employment of the fluctuation test for detection of accumulations of fluid in cavities of the body, or in abscesses which have resulted from inflammatory action.



[illegible] are numerous. [illegible] motion of a piston in [illegible] of a pendulum is also a to and fro [illegible] motion

306. The Pendulum.—The ideal, simple, or mathematical pendulum is a single heavy point suspended by a thread which is without weight. These conditions it is impossible to realize in practice, but they may be approached very closely. The compound or physical pendulum is that in actual use. In it a weight or bob is suspended by a solid rod, Fig. 111.

FIG. 111.

Pendulum.

If a ball of lead or platinum be suspended by a fine thread, we have an approach to a simple pendulum. If the distance from the point of suspension to the centre of the bob is three and a half feet, a pendulum will nearly beat seconds in its oscillations. If while it is beating, the string is suddenly caught between the thumb and finger, about half way between the point of suspension and the bob, and held steadily, the oscillations become more rapid, since the distance from the new point of suspension to the bob has been reduced one-half. As the free portion of string is made shorter, the oscillations are still more rapid. Releasing the string, and restoring the original length of the pendulum, the original rate of oscillation is regained.

Again throwing the pendulum into motion with the full length of string, and watching the time required to make an oscillation, we find that so long as the *amplitude* of oscillation, or length of arc through which it beats, does not exceed five degrees, the time of oscillation or beat is always the same.

We have here learned the two laws of the beat of the pendulum, viz.: 1st. *Within an arc of five degrees the time of beat of the pendulum is rigorously the same;* 2d. *The shorter the pendulum, the more rapid its oscillation.* It is these facts which enable us to employ the pendulum for measurement of time by clocks.

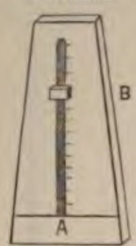
In (270) we have seen that the cause of the beat of the pendulum is gravity. In (299) we learned that the attraction of gravity varies on different parts of the earth's surface. It is, therefore, evident that the length of the mathematical seconds pendulum must differ at different latitudes. The extent of these differences at the level of the sea is shown in the following table.

St. Thomas	lat.	0° 25′	it is	39.0207	inches.
New York	"	40° 43′	"	39.1012	"
Paris	"	48° 50′	"	39.1285	"
Hammerfest	"	70° 40′	"	39.1948	"

307. The Metronome is an instrument employed by musicians for the purpose of beating time correctly. It is represented in

Fig. 112, and consists of a clock movement, which is enclosed in the base, A, of the apparatus. The pendulum is short and inverted, the weight or bob, B, being on the upper instead of the lower part of the rod. The bob is free to slide upon the rod, and thus different lengths may be given to the pendulum, and the rate of oscillation varied to meet requirements of the time to be beaten or measured.

Fig. 112.



Metronome

When in action the metronome emits a peculiar click, which serves to mark the time. It is employed in the measurement of time in physiological inquiries. In solution of such problems as the rate of nerve current, the more accurate device of the seconds pendulum, with or without the interruption of an electric current, is used.

308. The Balance Wheel.—If we conceive that the line of suspension of a pendulum is so shortened that the point of suspension and centre of oscillation pass within the pendulum bob, and finally reach its centre, the character of the oscillation becomes that which we see in a watch or chronometer balance wheel.

In a true balance wheel, where the point of suspension is accurately at the centre of the oscillating mass, gravity has no influence of importance. The forces which produce the movements are a main spring which drives the system of wheels of the apparatus; and a very fine spring called the hair spring, which is attached to the balance wheel, and acts upon it in an opposite manner to that of the main spring.

Both the pendulum and balance wheel are subject to variations in rate of oscillation, produced by variations in temperature. For the discussion of these, and means of correcting them, see (663).

If the point of suspension in a balance wheel is exactly at its centre, there is no motion of the mass out of the area it occupies when at rest. If, on the contrary, the point of suspension or centre of oscillation is on one side of the centre, the area occupied by the wheel in its oscillations is greater than its own area when at rest.

Applying these ideas to oscillations which the molecules in a mass of matter are executing, we can conceive that when a molecule is oscillating in a manner similar to that of a balance wheel, with the centre of mass and centre of movement coincident, one kind or form of force is the result. If, on the contrary, the centre of oscillation passes away from the centre of the molecule, conditions similar to those in a balance wheel

ed eccentrically exist, and the character of the force is it, just as the movement is different. In the first case, mple, the product might be electricity; in the second,

•

Rotation.—If the bob of a physical pendulum be a cir- wheel, mounted on its centre or *axis* of rotation, C, on ng it into action it moves like an ordinary um. If while in full swing, and when the ent is most rapid—that is, when the centre of is vertically under the point of support— b be suddenly checked at the projection P, object moving in the opposite direction, a of the oscillatory motion of the wheel will verted into movement of rotation upon its or axis, C. The same result arises if quickly the finger in a straight line we strike the ference of the wheel. Oscillatory and also novement may, therefore, be converted into ment of rotation.

FIG. 113.

Rotation.

tion may be of three kinds: 1st. *Centric*, the axis of rotation is in the geometric centre mass, as in the wheels of a watch or any machine. 2d. *Eccentric*, where the axis of ion is still within the mass, but not at the 3d. *Orbital*, where the axis of rotation is r to the mass, as in the movements of planets the sun.

tal movements differ greatly. Sometimes e circular, sometimes elliptical. They may parabolas or hyperbolas.

Molar Typical of Intramolecular Movements.—The move- of a planet with its moons around a central sun, the move- of double stars or suns around each other, and the com- that involves the movements of their attendant planets, interest the astronomer alone; they also demand atten- om the physicist, and suggest to him the idea that in ucture of molecules of different kinds of matter the atoms sing these molecules may also execute many different s.

an hypothesis would explain how from a single kind of tary atom all our so-called elements might originate, the nces between them being merely resultants of various ents which the constituent atoms of their molecules were ng.

odern theories of matter the molecules of elements are

supposed to consist of two, three, or more atoms. If the hypothesis that hydrogen is the original element be true, a molecule of lithium would contain a number of atoms seven times as great as that in a molecule of hydrogen, a molecule of carbon twelve times as many, and so on. In this case the diversity of movements that might arise among the constituent atoms of a molecule of lithium or of carbon may be readily conceived to determine the differences between the molecules of those substances.

Passing from elementary to compound molecules which in the case of organic bodies may contain as many as fifty atoms, we find that bodies which have the same number of atoms may present very different properties, dependent on the relation of the motions of the constituent atoms to each other.

The conversion of one kind of motion into another, which we have seen in the study of molar motions, would indicate the convertibility of one kind of atomic motion into another. The consequent possibility of the conversion of one kind of molecule into another, is, therefore, evident. See (28 and 29).

Not only motion, but the manner of grouping has its effect, as may be seen in the well-known kaleidoscopic appearances produced when several kinds of glass are grouped differently by merely revolving the instrument (11th, 480). If we conceive that the image of each piece of colored glass represents an atom endowed with a certain kind of motion, we quickly perceive how, as the grouping of these are changed, an almost innumerable variety of figures arise. In the case of molecules we can imagine a similar change produced as their atoms vary in their relations to each other. Thus all the shades of colors in flowers, and the infinite diversity of materials produced in the inorganic and organic worlds, may possibly arise.

Carrying out these suggestions, and those on conversion of motion in (305), to their ultimate conclusions, we find that the physics of the imponderables consists in the study of motions of molecules, while chemistry deals with the examination of movements of the atoms constituting molecules, and the manner in which they are grouped.

311. Centrifugal and Centripetal Forces or Motions.—The term centrifugal signifies flying from a centre of motion. No better example of this force or motion can be given than that of the ancient device of the sling, whereby a stone or other object is submitted to rapid orbital movement, and then suddenly released. At the moment of release the stone flies off in a straight line, driven, as we say, by centrifugal force.

The term centripetal signifies moving upon or towards the centre of motion. We have already referred to the influence of

centrifugal force in lessening the weight of objects at the equatorial region of the earth's surface (299). In that case gravity acts as a centripetal force; by it objects are attracted towards the earth's centre, and were they free to do so would move towards it; as it is, gravity is the centripetal force which binds objects upon the earth's surface and prevents the centrifugal force generated by rotation from launching them into space.

For illustration of centrifugal force and its action the apparatus known as the whirling table is employed. It consists of a platform A, Fig. 114, to which rapid rotation may be given by suitable multiplying machinery B. Any loose body laid on the surface of the platform is quickly thrown off when it is put in motion. So great is this force, that not unfrequently grind-

FIG. 114.

Whirling table.

FIG. 115.

Gyroscope.

stones and fly-wheels are torn to pieces when their revolution is very rapid. It is estimated that if the rate of rotation of the earth were seventeen times what it now is, gravity would be overcome, and objects would be tossed from its surface, probably to form a distant ring like that which accompanies Saturn.

The instrument known as the gyroscope, Fig. 115, offers an excellent illustration of the power of rotation to overcome gravity. It consists of a ring set in rapid revolution, while in this state it may be made to assume positions contrary to those which gravity produces.

312. Application of Centrifugal Force.—Among the practical applications of centrifugal force we may mention the removal of liquids from solids with which they may be intermingled, as in the centrifugal clothes-wringer, in which clothing is placed in a drum-like cage made of wire which is subjected to rapid rotation. Under these conditions the water is thrown off from the periphery of the drum, and the clothes come out almost dry.

The centrifugal milk tester is another recent application of this force, the milk is placed in a stoppered tube upon the whirling table, the axis of the tube being in the line of a radius of the platform of the table. Throwing the apparatus into rapid

rotation, the milk separates into the cream, curd, and aqueous solution of which it is composed.

Dr. Arnott says, "Were a man to lie down on a quickly turning horizontal wheel, with his head near the edge, he would soon fall asleep, or might die of apoplexy from over-pressure of blood on the brain." The suggestion is certainly worthy of examination. Applied in the manner he relates, it might prove of use in insomnia. Still more important results might be obtained by reversing the arrangement and placing a person suffering from congestion of the brain upon a whirling table with his feet towards the circumference, and his head over the centre of rotation. In that position the blood would be driven from the head to the opposite extremities, and relief attained. In other congestions and inflammations the same might be done, taking care to place the inflamed part over the centre of rotation.

The action of centrifugal force upon plants in their growth was made a subject of experiment by a French botanist some years ago. A series of vessels in which seeds had been planted were attached to the circumference of a large wheel to which rapid rotation could be imparted. The results of experiment showed that no matter how rapid the rotation, the centrifugal force thereby developed did not appear to have any influence upon the manner of growth of the plant. The stem and roots were always in the same straight line. There was no tendency to grow parallel to each other and outwards from the centre of rotation, as he expected would be the case.

SECTION III.

MACHINES AND INSTRUMENTS.

CHAPTER VI.

Relations of machines to force—The three orders of levers—Estimation of power in the action of levers—The wheel and axle—The inclined plane—The wedge—Scalpels and their management—The screw—The pulley—Friction.

313. Relations of Machines to Force.—The forces provided by nature for the accomplishment of innumerable kinds of work are few in number, wind, a fall of water, animal power. These limit nature's provisions of energy, which by agency of machines man has so adapted and controlled as to serve any purpose he may desire, from the act of lifting a rock or ship to the more delicate operations of setting type and printing a book.

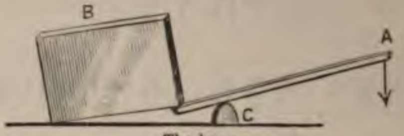
Wonderful and various as are the acts that machines can achieve, it must be clearly understood that in no case do they originate or increase the energy employed. They only modify it. As we watch a machine punching holes in plates of iron an inch in thickness, it looks as if it developed power, but it does not. It merely takes a rapid movement, representing a certain amount of energy, and converts it into a slower movement in which the same amount of energy is expended through narrow limits, but within the bounds of those limits it is almost irresistible.

The most intricate engines depend for their action upon a few machines of very simple form, to which the name of the *mechanical powers* was formerly given. They are the *lever*, *wheel and axle*, *inclined plane*, *wedge*, *screw*, and *pulley*. These simple machines are all of more or less interest to the physician, either as occurring in different parts of the human mechanism, or in construction of the instruments he employs.

314. The Three Orders of Levers.—The lever is so called from the Latin *levo*, to lift. It consists of an inflexible bar; when in use three additional elements are involved, viz.: A, the power; B, the weight; C, the fulcrum. According as these three elements vary in relative position to each other, a lever is said to be of the first, second, or third order.

In levers of the first order, the fulcrum is between the weight and power, or the middle one of the three; in the second form,

Fig. 116.



The lever.

the weight is in the middle; in the third, the power is in the middle.

All the joints of the body which are endowed with motion belong to one or another of the three orders of levers. Of the first order, the movement of the skull on the atlas is an example, the face being the weight, and the muscle in the back of the neck the power. Of the second order, the ankle-joint is an illustration; when we raise the body upon the toes, the weight is then in the middle, the ball of the great toe being the fulcrum, and the muscles on the back of the leg the power. Of the third order, flexing of the forearm on the arm is an example; the power being in the middle represented by the attachment of the biceps muscle, the hand the weight, and the elbow-joint the fulcrum.

Fig. 117.

Lever of first class.

Fig. 118.

Lever of second class.

Fig. 119.

Lever of third class.

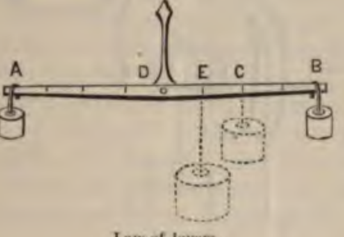
Among instruments in ordinary use, the first order of levers is represented by the elevator used to raise portions of bone in fracture of the skull, by scissors, and by bone or obstetrical forceps, which consist of two levers working against each other, the joint being the fulcrum. The second order is represented by the action of an oar in rowing, by nutcrackers, and wheelbarrows. The third order, by fire-tongs, and ordinary pincers of a surgical pocket case.

A curious double lever, known as the Stanhope lever or toggle joint, is represented in the human body by the knee-joint; it is a very powerful form of machine, and admirably adapted to the

purpose it serves in the body, viz., that of raising it from a squatting position.

315. Estimation of Power in the Action of Levers.—In the experiment represented in Fig. 120, the conditions of equilibrium between the two sides of a lever of the first order are shown. A weight of one pound at one extremity of the lever, A, will exactly balance a weight of one pound, B, at the same distance on the opposite side of the fulcrum, D. The same weight, A, will

FIG. 120.



Law of levers.

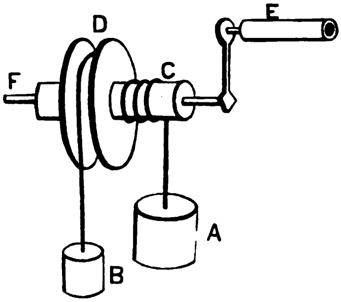
balance two pounds if suspended from C, which is half the distance between D and B; or it will balance four pounds if suspended from E, which is one-quarter the distance between D and B. Generalizing from these facts, and applying the rule to all forms of lever, we say, *that in levers the power is to the weight in the inverse ratio of their respective arms.*

If downward force be applied at A, the weight at B, which is at the same distance from the fulcrum, will be raised with the same velocity through the same distance as that by which A is depressed. The weight at C, on the contrary, will under similar circumstances be raised only one-half the distance, and at one-half the velocity with which A descends. At E the distance will be only one-quarter, and the velocity one-quarter. From which we deduce that in the action of levers, what has been gained in weight raised is lost in distance and velocity.

316. The Wheel and Axle acts upon the same principle as the lever. It has been called the perpetual lever. In Fig. 121, C is the axle, and D the wheel, both attached to the axis F. The wheel has a radius four times that of the axle C. These two measurements representing the relative lengths of the two arms of a lever, a power of one pound, B, applied to the cord on D, will raise a weight of four pounds, A, attached to the cord wound on the axle C. Viewing the respective radii of the wheel and axle, as the two arms of a lever, the rule for the estimation of the action of this machine is the same as for levers.

The wheel and axle is extensively used for hoisting heavy weights. In this form an endless rope passes around the wheel. The capstan used in weighing the anchor on ships is the same form of machine, in which the circumference of the wheel is dismissed, and only the spokes or radii employed. The winch used in raising water (135), and in many surgical appliances, is a wheel and axle in which only one spoke of the wheel is retained, as at E, Fig. 121.

FIG. 121.

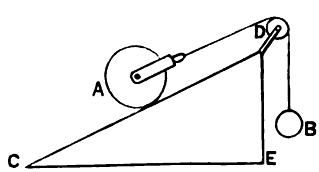


Wheel and axle.

The so-called *fusee* in a watch is an elegant example of the application of the wheel and axle to the production of a uniform force from the variable force exerted by a spring when unwinding. The systems of cog-wheels used in cranes for unloading ships, and of bands and wheels in lathes, are instances of the principle of the wheel and axle, and their action is to be determined by the same rule as that given for the wheel and axle.

317. The Inclined Plane is the third method of balancing forces of different intensities. The principle of its action is as follows.

FIG. 122.



Inclined plane.

Suppose a weight, A, rests on an inclined plane, the vertical height of which, D E, is just one-half its length, C D. It will be exactly balanced and retained in position by one-half its weight

applied vertically at B. The action of an inclined plane is, therefore, merely a modification of the lever.

In ancient times the inclined plane was largely used in elevating great weights. It is supposed that by this device the Egyptians raised to their present height the immense blocks of stone used in constructing the Pyramids.

It is curious to note how often the work required in the ascent of an inclined plane has been disregarded in the construction of country roads. The idea has been to build the road in a straight line from one point to another regardless of the hills that intervene. Roads have been thus carried over hills when they might as readily have been carried around their bases with little increase in distance, and complete avoidance of the labor required to surmount the elevations.

In the human body the principle of inclined planes is involved in the construction of the pelvis, for the purpose of producing changes in position of the head of the fœtus during delivery. The study of the action of these planes in the mechanism of labor, demands close attention on the part of obstetricians.

318. The Wedge may be described as an inclined plane forced in between substances or resistances, for separating or overcoming them. Estimation of their action is difficult, since the force employed is not one of pressure but of percussion. This power of transforming force is marvellous; even a ship may be raised by proper application of wedges.

Numerous examples of the wedge are seen in domestic as well as surgical appliances. All cutting implements are wedges, the angle of the edge varying according to their application. For working iron in a lathe a very obtuse angle is required in the cutting edge. In the blade of a pocket-knife, scalpel, or bistoury, on the contrary, the angle of the cutting edge is very acute.

319. Scalpels and their Management.—If the edge of the keenest scalpel or razor be examined under a microscope, it will be seen to be jagged or saw-like. Such blades may be pressed with considerable firmness against the skin without producing a wound, but the moment they are drawn like a saw over the surface, though the pressure be very slight, they immediately enter the flesh.

All surgical knives being made of steel, the greatest care should be taken to shield them from rust. So long as a steel surface is protected from moisture, oxygen has no action upon it, but if it be coated with ever so thin a film, it is quickly oxidized or rusted. To avoid this, steel implements should first be carefully cleansed, then thoroughly dried, and rubbed with leather before being placed in the case where they belong.

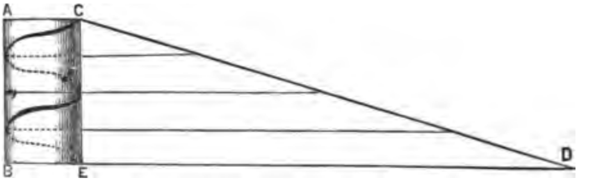
Since a knife, scalpel, or other instrument has received in its construction the proper angle for the work it is intended to do, care should be taken in sharpening to preserve that angle. If it is necessary to grind it down to restore the edge, it should be done on a true grindstone, the blade being applied and kept at the proper angle, and the action of the stone being from the back towards the edge. A thin or wire edge is thus obtained which is flexible, and may be turned by pressure towards one or the other side of the blade.

The next step is to remove the wire edge upon a hone or oil-stone; the surface of this should be as flat as possible. If it has been in use for some time and become hollow or concave, flatness should be restored by grinding it against the surface of a grindstone. The blade should be kept prone upon the hone throughout its application thereto. The movement should be from heel to point of blade with edge forward.

To give all the microscopic teeth which form the edge of a cutting blade a set in the same direction, the sharpening should be finished upon a strap of leather, which must also be flat; sometimes tightly stretched coarse canvas imbued with soap is used. In this operation the movement is reversed, the blade being carried from heel to point with the back forward. The surfaces should be kept flat on each other as in the preceding case, and applied alternately with very moderate pressure.

320. The Screw.—Form an inclined plane such as that described in (317), by cutting it out of paper, making the inclined

FIG. 123.



Screw.

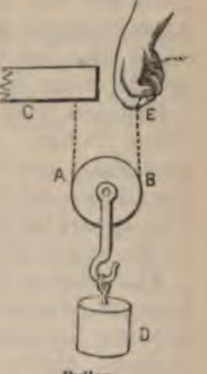
edge C D very long compared with the vertical edge C E. Applying the latter to a cylinder, A B, so that it is parallel to the axis of the same, and winding the narrow inclined plane on the cylinder, its edge will be found to have formed a screw upon the surface of the cylinder. We may, therefore, regard a screw as being virtually an inclined plane, and estimate its action in the same manner.

To the portion of the apparatus described the name of male element is given. The socket in which it works is called the female element or nut.

In the practical application of the screw, the handle by which it is driven acts as a lever; we, therefore, have usually a combination both of the screw and lever principles. The endless screw is the name given to a combination of a screw and a cog-wheel, by which one tooth of the cog-wheel is advanced for each revolution of the screw. In lithotrites, it is adapted to crushing the stone or calculus grasped between the jaws of the instrument. In the splints employed in treatment of certain kinds of fracture it is also used to produce the extension required.

In microscope work, very delicate screws are employed for measuring minute distances. Such are called micrometre screws. The head usually presents a graduation, by which small fractions of a revolution may be measured. Suppose the threads are $\frac{1}{100}$th of an inch apart, and the head presents 100 divisions, a movement of one division on the head is equivalent to a movement of $\frac{1}{10000}$th of an inch in the direction of the axis of the screw. The difficulty with such micrometres is irregularity in the thread, in which it presents an irregular instead of a regular inclination. To this the term drunkenness is applied. In accurate work error in this respect must be carefully studied to find the proper correction. In some cases drunkenness is corrected in the divisions of the screw head, these being made shorter or longer as the case requires.

FIG. 124.



Pulley.

321. The Pulley is another device by which masses of different weights may be made to balance each other by giving them varying velocities. In this case the pulley is movable, carrying the weight, with one end of the cord firmly fixed. Where the pulley is stationary, it merely serves to change the direction of a force, and does not interfere with its intensity.

In the figure, it is evident that one-half of the weight D is supported by the portion of the cord at A C, and the other half by the part at B E. If D weighs 100 pounds, it may be raised by a force of fifty pounds applied at E; but the force at E will have to draw in two feet of rope for every foot of height that D is raised.

By increasing the number of wheels or sheaves in the pulley block, we add to the number of folds of rope by which the weight is sustained, and thereby multiply intensity of the action. If, for example, we have four supporting cords, a force of one pound will balance or move a weight of four pounds attached to the movable block. In these combinations the fixed block has

no influence except to change direction of the motion as described above.

Combinations of pulleys are used occasionally in the reduction of dislocations of the hip-joint. A knowledge of their action is, therefore, of use to surgeons. In the body no example of combination of pulleys exist. Examples of the use of the fixed pulley for changing the direction of a force are offered by the patella, which signifies a pulley; and also by the tendinous pulley or loop at the inner side of the orbit, by which the direction of the contraction of the superior oblique muscle is changed and brought to bear upon the eyeball.

322. Friction.—Wherever there is motion of one substance upon another there is friction. All fluids and gases in their movements develop friction; especially is this true of solids. As we have seen (277), the force of adhesion which exists between different masses of matter affords a certain degree of resistance to any movement of such masses upon each other. Here, therefore, we find one cause of friction. Another, perhaps more potent, is roughness of the surfaces which come in contact with each other. Even the most highly polished surfaces are not mathematically true, but present projections and depressions of greater or less magnitude; these fitting into each other like the projections of cog-wheels, cause an equivalent development of friction.

Friction may be of two kinds: 1st. *Sliding friction;* and 2d. *rolling friction.* In the latter case the resistance to movement is practically much less than in the former. Wherever, therefore, the sliding can be converted into the rolling variety, it is done. The apparatus known as friction rollers offers the best example of the application of this principle.

The friction developed in the sliding of one surface on another depends to a certain extent on the intrinsic nature of the material forming the surface. For the examination of this problem an inclined plane, the angle of which may be varied, has been employed, and the angle of inclination at which movement commenced measured for different materials.

In Fig. 125 the results of these experiments are presented. The various unguents reduce friction to the lowest point; next follows friction of metal on metal; then of wood on wood; and lastly, of bricks and stones. Since the projections and depressions in two pieces of the same variety of material are more apt naturally to fit into each other, it is evident that substances of different kinds are less apt to develop friction than two bodies of the same nature, hence the use of iron as the axle or shaft, and of bronze in place of iron as the journal for the wheels or propellers of steamships. Another application of the same principle

is offered by the steel pivots and jewelled bearings or journals in a watch.

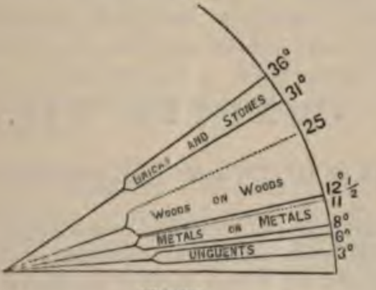
Three general principles govern the amount of friction developed between two plane surfaces, one being fixed and the other sliding.

1st. *Friction is exactly proportional to the pressure between surfaces.*

2d. *Extent of surface does not influence amount of friction.*

3d. *Friction is independent of the relative velocity of the sliding surface.*

FIG. 125.



Friction.

In the use of lubricating materials for reducing friction, different lubricators are to be employed for dissimilar substances: oils for metals; soap, grease, black-lead, for woods. An oil which reduces friction in metals, increases it when used for woods.

In the structure and operation of the joints of animals, great perfection is shown in the means adopted for reduction or avoidance of friction. The bones are covered by elastic cartilage, which is coated by a membrane presenting a wonderfully smooth surface; this, in its turn, is lubricated by a fluid called synovia, more lubricating than any oil, and renewed as fast as required. No human invention approaches in its perfection that attained in the construction of joints in animals; even rolling is generally substituted for the sliding form of friction, and every device which can reduce expenditure of muscular force to the lowest point is adopted.

SECTION IV.

TRANSLATORY MOLECULAR MOTION.

CHAPTER VII.

MOLECULES OF TWO MEDIA, ONE SET MOVING.

Varieties of molecular motion—Divisions of translatory molecular motion—Phenomena of capillarity—Circumstances influencing capillarity—Surface tension of liquids—Causes of capillarity—Laws of capillarity—Inclined surfaces and capillarity—Capillarity and floating bodies—Imbibition and absorption—Filtration—Draper's steam exhaust for filtration—Special filtration—Absorption of gases by solids—Disinfection by charcoal explained—Occlusion—Transpiration of liquids and gases.

To the contents of this Section the attention of students is especially directed, since the principles described are involved: 1st. In the absorption of chyme, chyle, and other fluids; 2d. In the circulation of blood, lymph, etc.; and, 3d. In the function of respiration, including introduction and conveyance of oxygen to the tissues, and removal of carbonic acid.

323. Varieties of Molecular Motion.—Molecular motion is of two kinds: 1st. *That taking place between molecules of two or more media;* 2d. *That existing in molecules of each individual medium.*

In the first case, the movement may be compared to that of direct molar motion, the molecules undergoing a change of their position in relation to surrounding molecules. This division includes the examination of capillarity, diffusion, osmosis, etc. In the second case, the molecules are subject to oscillatory, vibratory, or even rotatory motions, and do not materially change their location, or if slight change does occur, return instantly to their original position. This division deals with vibrations which produce sound, light, heat, and other so-called imponderable forces.

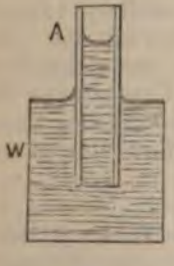
In accordance with the plan followed with molar motions, we shall first take up the examination of direct or translatory molecular motion, disregarding for the present the fact that the molecules of each medium entering into the action have, at the same time, the vibratory or other individual movements which belong to the condition of the medium they form.

324. Divisions of Translatory Molecular Motion.—This form of molecular motion may be studied under three conditions. First, where it occurs between molecules of two media, the molecules of one moving, while those of the other are stationary, as, for example, *capillarity*, *imbibition*, *occlusion*. Second, where it occurs between molecules of two media, the molecules of both being in movement, as in *diffusion*. Third, where molecules of many media are under consideration, all or a portion being in movement, as in *osmosis*.

325. Phenomena of Capillarity.—We have studied the attraction between molecules of different kinds as adhesion (281, 284). When such attraction leads to movement, the phenomena of capillarity or movement in capillary (*capillus*, a hair) tubes arise. As with adhesion, capillary phenomena are entirely independent of pressure of the air, and appear equally well in a vacuum.

The phenomena in question may be illustrated by dipping a

FIG. 126.

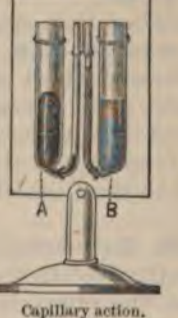


Capillary elevation.

FIG. 127.

Capillary depression.

FIG. 128.



Capillary action.

glass tube, A, $\frac{1}{10}$ of an inch bore, and open at both ends, into water, W, colored by any soluble pigment; ink will answer. The fluid will be seen to rise in the tube at once, as in Fig. 126. *There is capillary elevation.* The experiment succeeds also with certain other fluids; for example, alcohol. To secure the greatest amount of rise in a given tube, the interior should be chemically clean, and moistened with the fluid upon which the experiment is to be made.

Extending the experiment to other fluids, we find that while many conform to the observation related, others do not. Of these, mercury is a notable example; instead of being raised by the tube, it is depressed, Fig. 127.

The opacity of mercury presenting a difficulty in the way of seeing the result, we may remedy this by using the apparatus represented in Fig. 128. A tube, A, about an inch in diameter, terminates below in a narrow tube which is bent parallel to A. Pouring mercury into the large tube, it flows freely into the small one, but the level in the latter does not rise as high as in the former: *there is capillary depression*. Pouring water into the apparatus B, the level in the small tube rises above that in the large one: *there is capillary elevation*, as when the straight tube was dipped into ink. The advantage of this form of experiment is that it enables one to project the result by a lantern, and exhibit it to a large class.

Another phenomenon which appears in connection with capillarity is, that under the conditions which produce an elevation of liquid in the tube, the upper surface of the liquid is concave, its exterior limits rising higher in the tube than the interior portions. On the exterior of the tube also, Fig. 126, a similar elevation of the fluid is seen. Where depression takes place, the opposite result is produced, the surface of fluid in the tube is convex instead of concave, and in place of its rising on the exterior of the tube, it is depressed. To the curved surfaces in the tube, the names concave and convex meniscus are given.

Seeing that certain fluids are raised in capillary tubes, the question presents itself, What will happen in case the tube is broken off short of the point to which it can raise the liquid? Under such circumstances will it overflow? Experiment determines that it merely rises to the plane of fracture, and there is no tendency to the establishment of an overflow, nor of a current in the tube (345).

326. Circumstances Influencing Capillarity.—When a tube is moistened with liquid, the amount of elevation depends entirely upon the character of the fluid; the nature of the tube does not in itself have any influence. The amount of difference appearing for various liquids is shown by the following list, in which the diameter of the bore is one millimetre ($\frac{1}{25}$ inch), and temperature 18° C. Of all substances water rises the highest.

Water rises	29.79 millimetres.
Nitric acid	22.57 "
Alcohol	12.18 "
Essence of lavender	4.28 "

In capillary depression, since the fluid does not wet the tube, the amount of movement is influenced both by the nature of the tube and of the liquid.

Temperature affects both capillary depression and elevation. The movement diminishes with increase of temperature. Water, for example, which was raised 132 mm. in a tube at 0° C., was raised only 106 mm. in the same tube at a temperature of 100° C.

The condition of the interior of a capillary tube is an essential factor in its action. If, for example, it has been smeared with oil, it will permit it to rise, but will depress water. If it has been moistened with water, that fluid will rise, and oil will be depressed. According as the character of the interior superficies of a capillary tube varies, so does it possess what might be called a selecting power, permitting one liquid to enter or traverse it, and denying passage to another.

327. Surface Tension of Liquids.—All liquids act as though their superficial layer was subjected to tension which exerts a contractile force or pressure upon their interior mass. This is explained by the fact that the superficial molecules are held together by a greater cohesive force than those in the interior. Though this idea is regarded as a convenient fiction by some, others accept it as having an actual existence. Regarding it, Ganot says:

"Consider any particle at the surface of a liquid; it will be attracted in all directions except in that above the surface. The attractions acting laterally will compensate each other, and as there are no attractions above the surface to counteract those acting from the interior, the latter will exercise a considerable pull towards the interior. The effect of this is to lessen the mobility of particles on the surface, while those in the interior are quite mobile; the surface, as it were, is stretched by an elastic skin. This *surface tension*, as it may be called, is greater, the greater the cohesion of the liquid; it is well illustrated by blowing a soap-bubble on a glass tube; so long as the other end of the tube is closed the bubble remains, the elastic force of the enclosed air counterbalancing the tension of the surface; but when the tube is opened, the latter being unchecked, the bubble gradually contracts and finally disappears."

"Insects can often move on water without sinking. This phenomenon is caused by the fact that, as their feet are not wet by the water, a depression is produced, and the elastic reaction of the surface layer supports them in spite of their weight. Similarly a sewing needle gently placed on water does not sink, because its surface, being covered with an oily layer, does not become wet; but if washed in alcohol or potash it at once sinks to the bottom."

328. Causes of Capillarity.—Since capillary phenomena occur in an air-pump vacuum as well as in air, they cannot arise from action of the atmosphere. They originate in the relations of molecules of the liquid for each other and for the molecules of the tube in which they are placed. These actions, moreover, are confined to the superficial layer of the liquid and tube (326). The thickness of material forming the tube has no influence whatever on its action. It may, therefore, be said that capillarity is the resultant of the action of cohesion and adhesion; as one or the other is in the ascendant, so do phenomena vary. When adhesion of the fluid molecules for those of the tube is greater than their cohesion for each other, the liquid is raised and its surface is concave; when, on the contrary, cohesion of the fluid molecules for each other is greater than their adhesive attraction for the tube, the fluid is depressed and its surface is convex.

According to modern theory as stated by Deschanel, the following are among the causes producing capillarity:

1st. Surface tension of liquids, as described in the preceding article.

2d. For a given liquid in contact with a chemically clean solid, there is a definite angle of contact which is independent of the directions of the surfaces with regard to the vertical.

3d. This angle of contact determines the convexity or concavity of the free surface of the liquid.

4th. In capillary depressions and elevations the superficial film at the free surface is to be regarded as pressing the liquid inwards or pulling it outwards, according as this surface is convex or concave.

5th. Hence arise variations in the interior pressures of the liquid, a convex surface increasing, a concave surface diminishing them.

6th. The extent of rise or fall of liquid in a tube, is the balance between the tensions of the surfaces of liquids within and without the tube.

In his "Chemistry of Plants," Prof. J. W. Draper gives reasons for the opinion that the phenomena of capillarity, as well as of adhesion, are manifestations of electrical attractions and repulsions, since where they occur there is disturbance of the electrical conditions of the media entering into the action.

329. Laws of Capillarity.—If a number of tubes are employed, diameters of the channels of which are different, it is found that as the diameter of bore diminishes, its power to elevate fluid increases. Submitting these differences to as close a scrutiny as possible, Gay-Lussac evolved the following laws:

1st. Capillary elevations and depressions are inversely as the diameters of the tubes; all other conditions being the same. A tube half the diameter of a given tube, will raise the same liquid to twice the height.

If two flat glass plates are placed close together, and dipped into water, or other fluid, the fluid rises between the plates, but not to as great a height as in a tube.

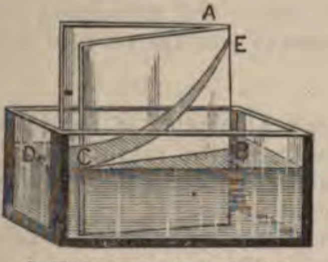
2d. Under similar conditions, capillary elevations and depressions, which occur between parallel plates, are to each other inversely as the distances between the plates. Under these circumstances the extent of movement is one-half that in a tube of the same diameter as the distance between the plates.

In the annular space produced when a solid cylinder is placed within a wide tube which nearly fills it, the height to which liquid rises is one-half that it ascends in a capillary tube of the same diameter as the width of the annular space.

3d. In a tube the bore of which is irregular, the diameter of the portion in which the meniscus forms determines the amount of elevation or depression.

330. Inclined Surfaces and Capillarity.—By means of inclined plates we may obtain a very interesting and instructive illustration of many points connected with the laws of capillarity.

FIG. 129.



Capillarity between inclined plates.

In Fig. 129, let A B represent two glass plates, the surfaces of which are perfectly flat and chemically clean, and B D a vessel containing water the level of which is in the plane B D. Holding the plates of glass so that they touch along their edges, A, and are separated to the extent of a tenth of an inch along C, and dipping them into water, the fluid rises between them. As the distance between the surfaces of the plates is less and less, the fluid rises higher and higher, finally arranging itself to produce a curve, C E. This result is a self-made graphic representation of the law—*that as the distances between two plates diminish, the height to which liquid is raised increases.*

331. Capillarity and Floating Bodies.—The mutual attractions and repulsions shown by small bodies floating freely on water, are governed by the following laws:

1st. If both floating particles are moistened by the liquid, and sufficiently close to each other to destroy the natural level of the water, attraction results. The experiment may be made with balls of cork upon water.

2d. If neither of the floating particles is moistened by the liquid, the same result happens when they are sufficiently near to each other. For example, pellets of wax.

3d. If one particle dampens and the other does not, they repel one another when placed in close proximity. Example, cork and wax on water.

It is curious to note that these three laws are the reversed counterpart of Du Faye's laws of electrical attractions and repulsions (770).

As in the case of other capillary phenomena, the above movements are now explained by the theory of surface tension. Another example of the same class of actions is seen when a piece of camphor is placed upon hot water; it immediately rushes about, often executing rotatory movements, first in one direction, then in another. These are produced by diminution in the surface tension of the water as it dissolves the camphor. Surface currents radiate in all directions from the particle of camphor, and as the rate of solubility varies in different parts, the pressure varies, hence the movement and changes therein. A pellet of potassium or sodium on cold water exhibits similar movements.

332. Imbibition and Absorption of Liquids.—In a physiological sense imbibition refers to the taking up of fluid by an inanimate solid, while absorption is applied to the same action in a living animal, or plant surface, or in a medium. In physics they are equivalent terms for a modified form of capillary attraction, in which capillarity is the result sometimes of clustered tubes, or, again, of fissures. Examples of this action are offered by a mass of sponge which by its porosity takes up nearly its own bulk of water. In like manner a glass tube filled with sand will imbibe a considerable quantity of water, raising it above the original level. Wicks employed in lamps act after the same fashion; indeed, they may be regarded as bundles of capillary tubes.

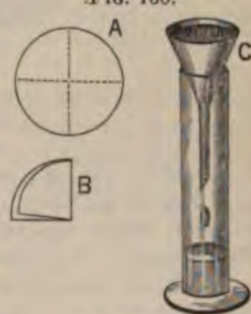
The upper rooms of a building the foundations of which are in damp soil may in this way become damp, moisture passing from brick to brick throughout its whole extent. A few threads, or the end of a towel hanging over the side of a basin of water, will act as a capillary siphon, and in time empty the basin.

In the general use of these terms imbibition is confined to liquids, absorption when speaking of liquids and gases.

In the practice of surgery the use of lint is an example of the application of imbibition. In their ordinary condition the absorptive power of lint is much greater than that of cotton. Recently, however, cotton has been prepared in such a manner as to increase its absorptive property, and it is extensively employed as a substitute for lint. Another instance of the application of absorptive property, is the use of powders of various kinds on the person for taking up excretions of the superficial glands. The more effective consist largely of starch, and of the spores of cryptogams, among which lycopodium may be mentioned.

333. Filtration.—Upon this process chemists depend mainly for the means of separating solid and liquid substances. It consists in the application of the absorptive power of unsized, bibulous, or filtering paper as it is called. The best is nearly pure cellulose, and is sold as Swedish filtering paper. The paper is cut into circles of different diameters according to the quantity of material to be operated upon. Having selected a piece of suitable size, it is folded twice along the dotted lines shown at A; thus the quadrant B, is obtained, consisting of four layers of paper. These are separated, to give three on one side and one on the other; a conical cup is thus formed, which is fitted to the interior of a funnel as at C, and the funnel placed in a cylindrical vessel. Fig. 130.

FIG. 130.

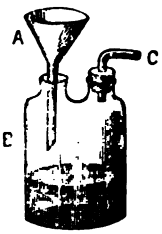


Filtration.

To secure proper action of the filter, the paper cone should fit the interior of the funnel as accurately as possible; the first action involved is absorption of the fluid portion of the contents of the filter by the bibulous paper; this passing to the exterior of the paper enters the annular space between the paper and funnel, where it is again submitted to the action of capillarity, and the outward flow of liquid assisted. The rapid conduction of this portion of the operation depends largely upon the accuracy of fit between the filter and funnel. Hence care should be taken to select funnels of the proper angle. This is readily done by trying with a paper cone prepared in the manner described.

The rate of filtration may be greatly favored by adapting the funnel, A, Fig. 131, to a two-necked bottle, B, and establishing a

FIG. 131.

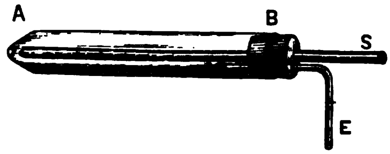


Rapid filtration.

partial vacuum therein by connecting the tube C with a filter pump (177). To support the point of the filter and protect it from the effects of increased pressure, a small cone of platinum foil is dropped into the apex of the funnel.

334. Draper's Steam Exhaust for Filtration.—When a column of water sufficient for working a Bunsen pump is not available, a device, of which I published an account in the London "Philosophical Magazine," for May, 1870, may be used. Its essential parts are represented in Fig. 132. A B is a wide tube, drawn to a small opening at A, and closed by a cork at B. Through the cork a tube, S, passes which terminates in a fine opening near the end of the large

FIG. 132.



Draper's steam exhaust.

tube at A. When steam under pressure is passed through S, and the small openings of the two tubes are properly adjusted to each other, exhaustion is produced in the interior of A B. By means of the tube E this rarefaction may be applied to the tube C of the filter bottle, Fig. 131. By a pressure of one atmosphere in the steam boiler, an exhaustion equal to 8 inches of mercury is easily attainable in the filter bottle.

When the tube E is disconnected from the filter bottle, and air permitted to enter freely, the mixture of air and steam which issues from the nozzle of A is a very grateful and soothing application to the surface of the skin, and I have suggested its use in inflamed conditions of this organ, as, for example, erysipelas.

334 A. Special Filtration.—By filtration, various objectionable substances may be separated from water. The action is, properly speaking, chemical, and consists in the oxidation of noxious bodies. They are of sufficient physical interest to command our attention.

1st. Filtration by masses of *compressed charcoal* is recommended as deodorizing and clarifying. These filters, however, very quickly become clogged, and in their interior germs of various kinds develop. They are not employed to any extent.

By *finely divided charcoal.* In this process, a funnel-d porcelain vessel, through which many holes are punc- is fitted mouth down and water-tight to an opening in ttom of a cylinder, which holds the water to be purified. unnel is covered by asbestos cloth, fastened with string of ame material. Finely divided charcoal is then mingled enough water to cover the funnel, and poured over it. As ater drains through, it leaves a covering of charcoal on the os cloth. The space between the funnel and cylinder be filled with coarse charcoal.

filter being thus prepared, fluid is poured into it. It through perfectly clear and well adapted for use in stic economy. As it percolates, fresh portions may be , and the action kept up for days or weeks, depending the character of water filtered.

Spongy iron filters consist of a tall cylinder with per-d bottom. In this cylinder a layer of coarse gravel, nch thick, is placed, upon this a layer of fine clear quartz then a layer of coarsely powdered pyrolusite about three s thick, and finally a layer of four or five inches of spongy Water poured on the top layer, is delivered below ed.

action of spongy iron in the presence of water and air emove all organic matter, at the same time forming a proto-f iron. In the layer of pyrolusite, this is peroxidized, and ited as red peroxide of iron; the lower layers of fine and sand arrest the peroxide, and the water flows out below rom admixture therewith.

. *Paper-pulp filters.* In preparing these is beaten to a pulp with water, and d into a vessel like that used for fine char-ilters. The asbestos thus becomes covered paper pulp, through which the filtration place. Modifications of this form are ised in the manufacture of beer and wine, arate certain impurities.

Fig. 133.

Absorption of gases by solids.

. **Absorption of Gases by Solids.**—If a tube, filled with dry ammoniacal gas at a urial trough, B, and a piece of freshly pre- charcoal, C, passed through the mercury ne gas, the charcoal will immediately begin sorb the gas, and the action will continue it has imbibed many times its own volume. coal made from boxwood possesses this rty in a very high degree. For this substance the absorp-ower is as follows, for different gases at ordinary pressures.

Those taken up in largest quantity are the more liquifiable. The amount increases with the pressure.

One volume of boxwood charcoal takes up of

Ammonia	90	volumes.
Hydrochloric acid	85	"
Sulphurous acid	65	"
Sulphuretted hydrogen	55	"
Carbonic acid	35	"
Carbonic oxide	9.4	"
Oxygen	9.2	"
Nitrogen	7.5	"
Hydrogen	1.8	"

The power of chestnut charcoal is still greater, one volume taking up 171 of ammonia, 108 of cyanogen, and 73 of carbonic acid. Pine charcoal has about half the power of boxwood coal. Corkwood coal, though very porous, has little or no absorbent power, neither has graphite.

These results are to be attributed to the property which certain substances possess of condensing gases upon their surfaces (284). It is evident that in the case of charcoal the extent of surface is enormously increased by its sensible pores, hence there is nothing very surprising in the power with which it acts.

336. Disinfectant Action by Charcoal Explained.—We have had occasion (284) to refer to the nascent condition, and energetic chemical action of gases condensed on the surface of metals in electric decompositions. This action offers an explanation of the power of charcoal, and certain other porous bodies, to destroy evil odors and emanations.

Whenever gases are submitted to surface condensation by solids their chemical activity is increased. The oxygen of air when absorbed by the pores of charcoal is condensed upon their surfaces; in this condition its chemical activity is greater, at the same time the gaseous constituents of the odors or emanations are also compressed into smaller compass in the pores of the charcoal, and their proneness to oxidation is in like manner advanced. The action, therefore, works both ways, the tendency of the oxygen and the oxidizable matter to go into union is increased, with the result of producing new combinations which would not be possible at ordinary temperatures in the absence of charcoal.

337. Occlusion.—Among metals platinum in the form of powder, called platinum black, possesses high absorbent power. So also does spongy platinum, which is said to condense 250 times its volume of oxygen at ordinary temperatures. The intensity of the affinity of oxygen and hydrogen condensed in the pores

gy platinum becomes so great that the temperature runs ıe point of ignition, and the hydrogen takes fire as in the iner lamp, Fig. 134, which consists of a small hydrogen or, A B C, in which when a certain quantity of gas has d the apparatus ceases to act. By means opcock, D, the gas issues through a fine impinges upon a small mass of spongy n E, with the result described.

FIG. 134.

Döbereiner lamp.

linary platinum be heated and then allowed in hydrogen, it absorbs four times its of gas. Palladium offers a still more re- le example, absorbing hydrogen not only ing but also when cold. If this metal is the pole of a voltaic battery in the electric osition of water, it will absorb no less than ıes its volume of hydrogen gas. Under ircumstances the density of the gas is usly increased. In this state it probably acts like a orming an alloy with the palladium.

gas which is taken up by metals in the manner described be removed by an air pump; for its expulsion elevation erature is required. Graham has called these phenomena rption of gases by metals *occlusion*, and conceives that cur under circumstances in which there are no pores. rd to this opinion the student is referred to (43), in which tence of sensible pores in gold and other metals is dis- If their existence is granted, the phenomena of occlusion a mere exaggeration of surface condensation of a gas s of a solid, as explained in (335).

xperimental illustration of the occlusion of hydrogen by m may be shown by making two long slender strips of tal the terminal electrodes of a voltaic battery, and im- them in water in a decomposition cell. One side of ip should be varnished to prevent contact with the water. ing the current through the cell the palladium pole from he hydrogen is evolved occludes the gas only on its shed surface; hence there is expansion on that side nd the strip becomes curved in accordance therewith. ng the current the strip which curved becomes straight, ıe opposite strip curves. Thus acting like a finger, each its turn designates the track the current of electricity g.

act of the occlusion of hydrogen by iron has led to ex- on of the meteors which from time to time come from ons of space to the earth. Whenever these contain iron nd to present occluded hydrogen, thus demonstrating

the existence of both of these elements in regions exterior to the atmosphere.

338. Transpiration of Liquids and Gases.—This term is applied to the passage of liquids or gases through capillary tubes under pressure. The experiments of Poiseuille have determined the following laws of *effusion* or *efflux*, both of which terms are employed.

1st. The flow increases directly as the pressure.

2d. With tubes of equal diameters, the quantities discharged in equal times are inversely as the lengths.

3d. The material of which the tube is made does not influence the result.

4th. For liquids in tubes of equal length but different diameters, the rate of efflux is as the fourth powers of the diameters.

5th. For gases, as the temperature rises the transpiration is slower.

CHAPTER VIII.

MOLECULES OF TWO MEDIA, BOTH SETS MOVING.

Solution and mixture contrasted—Diffusion between liquids or solutions—Crystalloids and colloids—Amœboid movements imitated—Diffusion between gases—Absorption of gases by liquids.

In this case we have the following conditions: 1st. The movement of the molecules of a solid among those of a fluid forming a solution. 2d. The movement of the particles of one fluid or solution into another. 3d. Movement of molecules of one gas among those of another. 4th. Movement of gaseous molecules among those of a liquid.

339. Solution and Mixture Contrasted.—In (283) the subject of solution has in part been discussed. It is a phenomenon very difficult to place, involving both simple adhesion and molecular motion.

Solution may be of two kinds: 1st. Chemical, in which there is more or less change of composition and properties, so that we do not regain the same solid on evaporating the solution to dryness. 2d. Physical, in which the properties of the body are

ot altered, and it can be regained in its original form by simple vaporation of the dissolving menstruum.

Movements attending either of these acts are largely due o increased gravity of the solution formed over that of the ıenstruum in which it is produced. They may be shown y the arrangement in Fig. 135. It consists f a glass cell, A, the sides and surfaces of which are flat and parallel. The space enlosed is about three inches square, and half n inch thick. A morsel of sugar, B, is susended by a platinum wire in the interior of he cell in the position indicated, and the rrangement placed upon the stage of a proection lantern and focussed upon the screen. Water is then oured into it until it reaches or covers the sugar, when, at once, he action begins, and the currents established form a most teresting spectacle.

Fig. 135.

Solution illustrated.

This action continues until the equilibrium between the coheive and adhesive forces described in (283) is attained; it then eases, and the solution is said to be *saturated.* The point of aturation for any solid in a given menstruum is, however, ariable for different temperatures, though the same at any iven degree.

In the case of the intermingling of fluids like alcohol and ater, there is no limit of solubility or saturation, either one ay or the other. These are called *mixtures.* In certain intances, the first stage of the preparation of such mixtures is ttended by change in temperature, as with sulphuric acid and ater. It is, therefore, thought by some that solution may, in hese instances, be a low form of chemical action or chemism.

On the other hand, there are cases in which two liquids do ot form mere mixtures, but true solutions which show a point f saturation; examples of this are offered in the relations of ater to volatile oils, many of which are soluble only to a efinite point, when the solution may be said to be saturated.

Certain mixtures separate easily, as those of fats in water and lbumen. These are known as *emulsions;* of this group fresh milk s an example. In time it separates spontaneously. Objection night be made to this instance, on the score of the chemical hanges that at the same time take place. Such objections are, owever, not valid in the separation of the constituents of milk y mere centrifugal action (312).

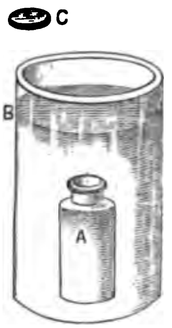
In true solutions of saline bodies, separation of the constituents nly takes place by the act of crystallization, when the point of aturation of any one of its components is reached.

340. Diffusion Between Liquids or Solutions.—Though all liquids ppear to resemble each other closely, there are nevertheless

essential differences between them. Water, for example, will intermingle freely and in all kinds of proportions with alcohol if agitated therewith, but not at all with certain oils. Water and alcohol not only form a mixture when shaken together, but also when merely placed in contact, the alcohol being carefully floated on the surface. Under these circumstances, in spite of the greater specific gravity of the water, it passes upwards to mix with the alcohol, and the light alcohol penetrates to the very lowermost layers of the water, until finally they form a uniform mixture throughout. To this phenomenon of the spontaneous intermingling of miscible liquids, the name of *simple diffusion* is given.

The laws which govern simple diffusion, or that form in which there is no barrier between the liquids, have been thoroughly investigated by Graham. The method he finally adopted was to take a wide-necked bottle, A, with a capacity of about four ounces. The edge of the lip of this was ground, and a disk of thin glass, C, fitted thereto. The bottle was filled with the liquid or solution to be examined, and the cover put in position. It was then placed in a jar, B, as is shown in Fig. 136, and the jar filled with distilled water to a height of one inch over the cover. Uniformity in this respect was an important element in all his experiments—the amount of water employed was about 20 ounces. The disk was then removed with as little disturbance as possible, and after the lapse of sufficient time replaced, and successive layers of the water removed, and their composition determined.

FIG. 136.



Diffusion illustrated.

Under this method of examination various solutions exhibited different powers of diffusion. The following table gives the times of equal diffusion.

Substance.	Minutes.
Hydrochloric acid	1.0
Chloride of sodium	2.3
Sugar	7.0
Magnesium sulphate	7.0
Albumen	49.0
Caramel	98.0

Elevation of temperature increased the quantity of solution diffused. The rate for hydrochloric being one at 15° C., was more than doubled at 49° C.

When substances which do not combine are mingled, that which is more diffusive passes out of the bottle more rapidly;

the two bodies are thus partially separated. Sometimes chemical decomposition results from this action.

341. Crystalloids and Colloids.—In the list of substances given in the preceding diffusion table, some are crystalline and some are amorphous. Of crystalline or saline bodies, magnesium sulphate is one of the least diffusible, yet it diffuses seven times as fast as albumen, and fourteen times as fast as caramel. Other bodies, as starch, dextrine, gum, hydrated silicic acid, resemble albumen and caramel in their low rate of diffusibility, and form a distinct group. To this group Graham has given the name of colloid or glue-like, in contradistinction to the saline or crystalloid substances which have so much greater diffusive power (347).

342. Amœboid Movements Imitated.—In connection with the phenomena of diffusion of liquids, I have for a few years past exhibited to my classes a very curious and instructive original experiment in which the actions seen in amœba under a microscope, are imitated with singular fidelity.

The apparatus consists of the cell described in (339). The inner wall must be perfectly clean. It is half filled with pure water, and placed upon a lantern stage. A layer of alcohol is gently poured on the water to the depth of about a tenth of an inch; the cell is then cautiously tilted to moisten one of its sides, and returned to the normal condition.

After a short time drops form on the surface of the glass. These are focussed upon the screen, in order that their movement may be seen to advantage. They are perfectly outlined, and move about extruding and withdrawing curious processes, exactly after the fashion of amœba. If they approach closely to each other they cohere, and become one. Thus far it is easy to conceive that one is watching the movements of amœba. But even more extraordinary motions are executed. From time to time, one of these singular protean forms approaches the surface of the liquid, and assuming the outline of a very short-necked flask, begins a rapid movement which is an exact counterpart of the act of drinking.

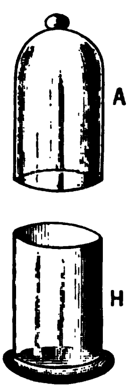
These marvellous movements on the wall of the glass cell continue for some time. I have often watched them for two hours continuously. As one gazes upon them as though fascinated, it is almost impossible to divert the mind from the idea that the motions are executed by some one of the lower forms of animal organisms. We look upon phenomena like those we have described, as one of the most characteristic features of animal life, yet we here find them executed by mere unorganized drops of fluid.

Though we have introduced the above experiment in this division of our subject, it is to be understood that in addition to the acts of diffusion on which they are based, other influences, such as evaporation and adhesion to the glass surface, are involved. The latter is a most essential element of success, for without proper attention to cleansing the cell, the experiment is not satisfactory.

343. Diffusion Between Gases.—Gases also diffuse when brought in contact with each other, and form a perfect mixture, no matter how great the difference in their specific gravities may be.

In Fig. 137, the interior of the jar H is first moistened with strong hydrochloric acid; it is thus filled with hydrochloric acid gas. It must be kept mouth upwards, as the gas is heavier than air. In like manner, the bell A is filled with ammoniacal gas, the operation being conducted at a distance from H, and the bell being kept mouth downwards to retain the light gas. They are then brought mouth to mouth. At once the gases intermingle in spite of their different gravities, white fumes of ammonium chloride appearing, which almost immediately fill the jars.

FIG. 137.



Diffusion between gases.

In the above arrangement one is impressed with the great rapidity with which gases diffuse when compared with liquids. The result grows out of the fact of the greater mobility of the gaseous molecules, and is a proof of the hypothesis that the particles of these elastic fluids are in constant active motion.

If the diffusion of gases into the atmosphere is hindered, by placing them in closed vials which communicate with the air by tubes about ten inches in length, and a small fraction of an inch in diameter, the relative rate may be easily determined. From experiments, conducted in this manner, Graham arrived at the following results:

Relative diffusibility of gases into air.

Gas.	Sp. gr.	Rate.
Hydrogen	1	94.5
Carb. hydrogen	8	62 7
Ammonia	8.5	59.6
Olefiant gas	14	48.3
Carbonic anhydride	22	47.0
Sulphurous anhydride	32	46.0
Chlorine	35.4	39.5

Showing that the lighter the gravity, the more rapid the rate of diffusion.

Vapors also move into each other, and into gases. Under all circumstances of diffusion of gases and vapors, they never again separate by virtue of their differences, but constitute a uniform mixture until decomposed by suitable chemical means.

344. Absorption of Gases by Liquids may be either chemical or physical. In the first case, the amount taken up is definite and fixed, as of carbonic acid and chlorine in a solution of caustic soda. In the second, the proportion varies with temperature and pressure.

As regards the effect of pressure on physical solution of gases, the law is very simple, the amount dissolved varying almost directly as the pressure. For this result, we find an explanation in Boyle's or Mariotte's law (223). The effect of temperature cannot be so readily brought under the influence of any stated law. In a general way, gases are less soluble at high than at low temperature; there are, however, many exceptions: hydrogen, for example, is equally soluble in water between 0° and 25° C.

CHAPTER IX.

MOLECULES OF MANY MEDIA, A PORTION MOVING.

Establishment of continuous flow in capillary tubes—The endosmometer—Osmosis—Dialysis—Applications of dialysis—Osmosis of gases through porous media—Hygienic importance of osmosis of gases—Osmosis of gases through metals—Vitiation of air by stoves—Capillarity and chemism.

WHERE the molecules of all the media present are in movement the conditions are similar to those given in Chapter VIII. Where the molecules of one of the media are at rest, the conditions are a combination of those presented in Chapters VII. and VIII., and new and very important phenomena arise. To these we shall devote special attention.

345. Establishment of Continuous Flow in Capillary Tubes.—In (325) it is stated that a capillary tube does not allow a liquid to overflow when it is broken short of the height to which it can raise the liquid.

This is true so long as nothing is done to remove the liquid as it reaches the fractured extremity. If, on the contrary, the

liquid being water, we from time to time touch the end of the tube with a slip of blotting or other bibulous paper, the fluid is taken up by it, and more rises to fill its place. In like manner, the fluid being alcohol, it may be evaporated at the end of the capillary tube, and an upward current thereby established.

We have seen in (340) that liquids diffuse into each other. If, therefore, we make a capillary tube, C, the means of communication between a vessel, A, containing alcohol, and another, W, filled with water, as fast as the contents of W reach A they will be removed by diffusion into the larger mass of alcohol, and a continuous flow from W to A established. On the other hand, as fast as the alcohol passes through the capillary to W, it will in its turn be removed and a flow established from A to W.

FIG. 138.

Flow in capillary tube.

Thus through a fine tube two liquids may be moving in opposite directions at the same time under the combined influence of capillarity and simple diffusion. In such a movement the liquid which has the greater capillarity and diffusive power will have the advantage, and move in larger quantity or more rapidly.

346. The Endosmometer was so called by its inventor, Dutrochet. It consists of a glass tube, E, a couple of feet in length, to the lower extremity of which a small bladder, A, is attached without leakage. The bladder being filled with alcohol the arrangement is immersed in water contained in the vase W.

FIG. 139.

Endosmometer.

The temperatures of the alcohol and the water being the same, when the bladder is first placed in the water the liquid occupies the lower part of the tube E. Soon, however, it begins to rise, and forming drops at E, these fall one after another and a considerable overflow of a mixture of alcohol and water may be collected in a suitably placed vessel V.

Various other liquids can be substituted for alcohol in the bladder A, with a similar result, viz., accumulation of fluid therein. Among such articles are syrup, milk, gum water, albumen, or any solution denser than water, and miscible therewith. As a rule, accumulation of fluid takes place

on the side of the denser liquid; to this there are, however, exceptions, alcohol being one of the most notable.

Since in the experiments we have described there is a movement towards the interior of the bladder, and an accumulation therein, Dutrochet gave to this phenomenon the name of *endosmosis*, from two Greek words signifying inward movement.

The explanation of the action of the endosmometer is furnished in (345). The membrane which separates the two liquids is to be regarded as a porous partition. These pores, whatever their shape or character, may be conceived to be equivalent to short capillary tubes or crevices, extending from one surface of the membrane to the other and terminating at each end in open mouths; one in contact with alcohol, the other with water.

Under these conditions since water moves along capillary crevices with greater facility, accumulation is in the interior of the bladder, and endosmosis results. The exceedingly minute calibre of the pores in such membranes gives them enormous power, according to the laws of capillarity (329).

347. Osmosis.—In the preceding article we have dealt only with the result as far as the interior of the bladder is concerned, and have seen that there is an accumulation of a mixture of alcohol and water therein. Let us now examine the condition of the fluid on the exterior of the bladder. By analysis we find that it is no longer pure water, but that a certain proportion of alcohol is present. While water has been passing inwards into the bladder, alcohol has been passing outwards to the water. To this movement the name of *exosmosis* was given by Dutrochet; the double action is included under the term osmosis, which was introduced by Graham.

From the above, it is evident that often where endosmosis exists, exosmosis is present. The movements are in opposite directions, and at different rates. In some cases movement is only in one direction.

The exhibition of exosmotic action may be readily shown by reversing the charging of an endosmometer, putting water in the bladder, and filling the vase with alcohol. Under these conditions instead of the wall of the bladder becoming more tense and forcing liquid up the tube, it becomes flaccid, showing a loss of its contents.

So strong are these osmotic actions that they can often overcome feeble chemical affinity, in the case of dilute alcohol for example. Since water moves much more rapidly through a membrane than alcohol, if a bladder containing dilute alcohol is suspended in a current of air to promote evaporation from its exterior, the alcohol in the interior will become stronger and

stronger, until at last it is almost completely dehydrated by the exosmotic action on the water and its removal by vaporization.

348. Dialysis.—Liquids not only traverse porous membranes, but they also pass or diffuse through jelly-like media or septa, which are supposed not to possess pores in the ordinary sense of the term, though about this there may be some question, as they certainly have physical pores if they may not present sensible ones. This diffusion through jelly-like septa Graham has called dialysis. Deschanel says such septa act as solvents taking up crystalloids on one side and surrendering them on the other.

The best substance for a dialytic medium is parchment paper. It is unsized paper which has been immersed for a few seconds in sulphuric acid diluted with one-third its bulk of water, and then washed with weak ammonia and dried. Thus treated the paper becomes very tenacious or parchment-like. If dipped in water, it swells and becomes translucent. Parchment paper may also be prepared by a solution of chloride of zinc.

In (341) Graham's division of bodies into crystalloids and colloids has been discussed. The colloid group may still further be divided into those somewhat soluble in water, and those almost absolutely insoluble. To the latter belongs parchment paper.

By simple diffusion (340), a mixture of less diffusible or colloid bodies, and highly diffusible or crystalloid bodies, undergoes partial separation. The difference in the relative rate of passage of colloids and crystalloids is enormously increased when an insoluble colloid septum like parchment paper is introduced between the mixture and the water. Through such a septum the passage of soluble colloids is resisted. It is this fact which is applied by Graham in his dialyzer.

Fig. 140.

Dialysis.

A convenient form of this instrument is represented in Fig. 140. It consists of a hoop of glass or other material, A, the lower opening of which has been closed by parchment paper put on wet and fastened in position by a string or rubber band. It should pass up on the outside of the hoop higher than the

level the fluid is to occupy on the interior. We may be satisfied of its soundness by sponging it with pure water on the inside, and seeing that no wet spots form on the outside. In case they do, the openings may be stopped by a varnish of albumen, which is then coagulated by heat. Parchment bags may be made in the same way.

The mixture to be dialyzed is introduced into the hoop to a depth of about half an inch, and the arrangement placed in a vessel of water, B, its lower surface immersed to a slight depth. After the lapse of 24 to 48 hours, the operation will be complete, the colloids remaining in the dialyzer, and the crystalloids being almost entirely in the water on the outside. From this dilute solution, the crystalloids may be obtained by evaporation, precipitation, or any other suitable method.

349. Applications of Dialysis.—Among these, three are of especial interest to the physician, not only on account of their intrinsic value, but because they may suggest other instances in which this method may be applied.

1st. Soluble peroxide of iron, also called dialyzed iron, is prepared by this process; the operation is described by Graham, as follows: Perchloride of iron solution is first saturated with peroxide of iron by adding carbonate of ammonium as long as the precipitated oxide continues to redissolve on stirring. Prolonged exposure increases the quantity of iron dissolved. The red liquid formed is already somewhat colloidal. It is then dialyzed in the usual way for many days.

In an experiment recorded by Graham, he began with a liquid in the dialyzer, containing 5 per cent. of solid perchloride of iron, which held in solution about five equivalents of iron. In the course of eight days, it consisted of about 97 per cent. of peroxide to 3 of acid. In nineteen days, the hydrochloric acid was reduced to 1.5 per cent. The solution was then transferred to a vial, in which it remained fluid for twenty days, and then jellied spontaneously.

Water containing one per cent. of this substance has the dark red color of venous blood. When sufficiently concentrated by boiling, a coagulum forms spontaneously, which closely resembles a clot of blood, though more transparent. In its fluid state, soluble peroxide of iron is the most useful and agreeable form in which this metal can be administered.

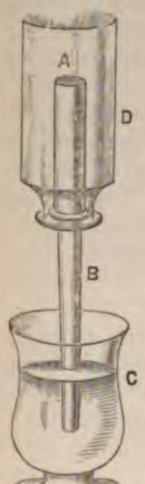
2d. In the detection of poisons the process of dialysis is a most valuable adjunct, by which crystalline poisons may be separated from the organic material with which they are mixed. Being thrown on the dialyzer, and submitted to its action for a couple of days, the separation is almost complete. On evaporating a portion of the exterior liquid, and allowing it to crys-

tallize over sulphuric acid, if necessary, we may often detect at once the presence of noxious agents, which present characteristic forms of crystals. To the concentrated diffusate the ordinary processes of qualitative and quantitative analysis can be applied, and its character determined.

3d. In the examination of urine, dialysis has been applied for the separation of the crystalloid constituents, and urea has in this way been obtained in so pure a condition as to yield its characteristic crystalline form.

350. Osmosis or Diffusion of Gases Through Porous Media.—The outward and inward movements of gases through porous barriers may be demonstrated by the arrangement in Fig. 141. It consists of the porous earthenware cell of a Grove battery, A, to the mouth of which a glass tube, B, has been attached air tight. The lower end ot the tube dips under the surface of water in the vase C.

FIG. 141.



Diffusion of gases through barriers.

At first the level of liquid in the tube B and vessel C is the same, and both are filled with air. Enclose the porous jar A in a bottle, D, filled with hydrogen; that gas instantly flashes through the pores of the battery cup, and mingles with the air therein, accumulating to so great an extent in the interior that it rushes out in bubbles through the water. When the escape of bubbles has nearly ceased, remove the bottle D, and expose A to the air. Instantly a movement in the opposite direction takes place, the water rises rapidly in the tube, and almost reaches the porous jar in spite of the downward action of gravity.

Here, we have endos- and exosmosis exhibited in a remarkable manner, and far more energetically and promptly than in the case of liquids. This, a little reflection would have led us to expect, considering the greater mobility of gaseous molecules, which, we have already seen, exerts so great an influence on the phenomena of simple diffusion.

The details of the action are as follows. At the beginning, the interior and pores of the vessel A are filled with air, into this the hydrogen diffuses, and since its diffusion power is much greater than that of air there is rapid accumulation in the interior of A. This movement continues until the relative proportions of hydrogen and air in the inside of A, and in the bottle D on the outside are the same. It then ceases. On uncovering A, and exposing it to the air, the conditions are reversed. Inside of A there is a mixture of gases, the chief

constituent of which is hydrogen. On the outside there is air. To this the hydrogen instantly diffuses. In its outward passage a partial vacuum is formed, and to fill this the water rises in the tube, forced up by atmospheric pressure.

In the example of osmosis we have here examined, a special point of interest is the use of an inorganic septum, showing that the phenomena of osmosis are not confined to organic media. In place of the porous jar we might have used a septum of India rubber or bladder, but the results would not have been as striking.

Another matter of interest is the fact that the movement is more rapid than when gases are freely exposed to each other, as in simple diffusion (343). This is to be attributed to the condensing action which all surfaces and pores exert upon elastic fluids.

351. Hygienic Importance of Osmosis of Gases.—The osmotic movement of gases through inorganic bodies is a matter of considerable importance from a hygienic point of view. As we have seen hydrogen flash instantly through the porous vessel A, so will it pass through one or many thicknesses of brick, or through the plaster of which walls are formed. A person may even blow through a brick. Gaseous or vaporous emanations in one apartment of a building thus find their way into other rooms. The effluvia arising from leakage in a water-closet in one location, freely penetrates to all parts of a house.

To a certain extent, free passage of gases through plaster, brick, and similar barriers, may be prevented by coating them with several thicknesses of paint. As regards floors, the use of tiles and slabs of marble is for this reason to be preferred to that of wood, unless the latter is of the pitch pine variety. Movable rugs are superior to carpets, since they secure better opportunities for cleanliness.

In like manner, hydraulic cement spread on the cellar floor of a house built on made ground is a very imperfect protection against the passage of noxious gases evolved from the earth. It does not keep moisture out; it would be greatly improved if saturated with bitumen, which should be applied hot and pressed with heavy hot rollers, as in laying bitumen pavements.

The hygienic benefits arising from sleeping in a tent during a camping-out excursion are largely to be attributed to purity of the air which results from free gaseous osmosis through the canvas of the tent. On well-drained ground, with a close boarded floor covered with rugs, and double canvas overhead, a tent offers in fair weather better hygienic conditions than can be attained in most houses.

352. Osmosis of Gases Through Metals.—In iron or steel cylinders, hydrogen may be compressed under a pressure of 50 or more atmospheres, and preserved therein without sensible loss for an indefinite lapse of time. This statement is perfectly true while the temperature is that which we ordinarily find existing in air; but if this condition be changed, and the temperature raised to a red heat, iron can no longer retain gas, not even at ordinary pressures. With elevation of temperature its properties in this respect are so altered that it permits the diffusion of hydrogen with a facility rivalling that of the porous battery jar employed in the experiment (350).

Not only iron, but platinum and other metals, permit the osmosis of gases at high temperatures even more readily than India-rubber does at the ordinary temperature of air. Graham found, for example, that a square metre of caoutchouc 0.014 millimetre thick would permit the passage of 129 cubic centimetres of hydrogen at 20° C. A platinum tube 1.1 millimetre in thickness and the same extent of surface, during the same time permitted the exosmosis of 489 cubic centimetres of that gas.

353. Vitiation of Air by Stoves.—At first glance the principle discussed in the preceding article would appear to be of little practical value to physicians. Not so, however, when we examine it in all its bearings.

The economic solution of the problem of warming, in the United States, consists in the almost universal use of stoves or hot-air furnaces, in which the burning mass is in direct contact with a vessel of iron; under these conditions the iron becomes red hot, and in that state is permeable to gases.

Among the products of combustion in a stove or furnace there are two gases which exert a highly noxious action upon the human economy; these are carbon monoxide or carbonic oxide, and carbon dioxide or carbonic acid gas. Both pass freely through red-hot iron, and may be readily found by collecting the layer of air immediately in contact with the exterior surface of the red-hot iron, and submitting it to chemical analysis.

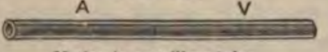
Osmosis of these gases may be prevented by lining the interior of the combustion chamber with soapstone or fire-brick. These are very permeable to gases, but by their use iron does not have its temperature raised high enough to allow them to pass; their escape is, therefore, prevented.

The use of such a lining involves considerable loss of heat. This, however, can be counteracted by increasing the surface of pipes or tubes through which the products of combustion pass. Various devices in the form of drums have been applied to the accomplishment of this purpose.

354. Capillarity and Chemism.—In (345) we have seen that by means of physical agencies a continuous flow may be established in capillary channels. Suppose that in addition to physical phenomena we also have to deal with changes in chemical affinity or chemism under conditions like those which follow: What will the result be?

Let A V, Fig. 142, represent a capillary vessel, and grant that a liquid having an affinity for its walls enters at A, drawn in by capillarity. Under ordinary conditions, the liquid would

FIG. 142.



Motion in a capillary tube.

simply pass into the tube, but a continuous flow would not be established. If as the liquid passed towards V its affinity for the capillary walls was gradually lost, it is evident that conditions favorable to an unbroken flow would then exist. The inert liquid would be pressed out by the onward movement of the active fluid entering behind it. Loss of affinity would be equivalent to a removal of the liquid as fast as it reached a certain position and movement would result. Suppose A to represent arterial blood and V venous, moving in a capillary, and the bearing of the proposition is evident.

In the preparation of the articles thus far forming this Section, we have been compelled to resort to considerable condensation. Those who desire a more extended acquaintance with the subject will find it fully discussed in Graham's "Chemical and Physical Researches," and also in Watt's "Dictionary of Chemistry."

CHAPTER X.

PHYSIOLOGICAL APPLICATION OF TRANSLATORY MOLECULAR MOTION.

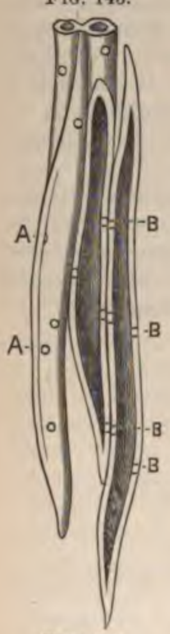
Ascent of sap in trees—Absorption in animals—Harvey's mechanical theory of circulation—Insufficiency of simple mechanical theory of circulation—Draper's physico-chemical theory of circulation—The physics of respiration.

355. Ascent of Sap in Trees.—Compared with circulation in animals that in plants is the more remarkable, since it is accomplished by osmotic action alone, without the agency of a heart

or other mechanical pumping organ. In the Sequoia Wellingtonia of the Sierra Nevada, the sap rises to a height of four hundred and fifty feet above the ground. A giant Eucalyptus, measured by G. Klein, on the Black Spur ten miles from Healesville, in Australia, reaches the height of four hundred and eighty feet, yet its topmost leaves are freely supplied with the fluids necessary for their nourishment.

To comprehend the manner in which this surprising result is attained, it is necessary to examine briefly the structure of the parts by which it is accomplished. In exogenous plants, or those having a true bark, the circulatory process is almost entirely confined to the new wood or outermost layer of wood, called sapwood or alburnum, and to the inner layer of bark, called the liber. At their junction these constitute the so-called cambium layer, which consists of young and forming cells, of which the innermost are being continually added to the wood, and the outermost to the bark. It is in the wood cells that ascent of sap usually takes place.

FIG. 143.



Wood cells.

In his "Lessons in Botany," Prof. Gray gives the following description of the wood cells or fibres. "These are small tubes, commonly between one and two thousandths, but in pinewood sometimes two or three hundredths of an inch in diameter. Those from the tough bark of the basswood are only the fifteenth hundredth of an inch wide. Those of buttonwood are larger. Fig. 143 also shows the way wood cells are commonly put together, namely, with their tapering ends overlapping each other—spliced together, as it were—thus giving more strength and toughness to the stem.

"Wood cells, like other cells (at least when young and living), have no opening; each has its own cavity, closed and independent. They do not form anything like a set of pipes opening one into another, thus conveying an unbroken stream of sap through the plant, in the way people generally suppose. The contents can pass from one cell to another only by getting through the partition in some way. So short are individual wood cells generally, that to rise a foot in a tree like the basswood, the sap must pass through about two thousand partitions.

"But although there are no holes (except by breaking away when old), there are plenty of thin places which look like perforations, and through these the sap is readily transferred from

one cell to another. Some of these are exhibited in Fig. 143, where A and B, looked directly down upon, appear as dots or holes, while in profile the cells seem as though they were cut through. The latter view shows what they really are, namely, very thin places in the thickness of the wall. A thin place in one cell exactly corresponds to one in the contiguous wall of the next cell."

Passing from the stem to the root the structure may be regarded as being the same until the rôot tips are reached. These, according to Prof. Gray, "are entirely composed of soft, new, and very thin-walled cellular tissue; it is only further back that some wood cells and ducts are found. The moisture (and probably also air) presented to them is absorbed through the delicate walls, which, like those of the cells in the interior, are destitute of openings or sensible pores."

Exteriorly, in the air, plants terminate in leaves; "these consist of both a woody and a cellular part. The woody part is the framework of ribs and veins; they serve not only to strengthen the leaf, but also to carry in the ascending sap, and distribute it by veinlets throughout every part. The cellular part is the green pulp and is nearly the same as the green layer of the bark, so that a leaf may be properly enough regarded as an expansion of the fibrous and green layers of the bark. In most leaves the green pulp forms two principal layers: an upper one facing the sky, and an under one facing the ground. The upper side is constructed to bear the sunshine, and if the leaf is turned it twists itself to enable the proper side to receive the light."

"The moisture exhaled from the leaf escapes chiefly from the under surface, by the stomata or breathing pores. Of these few or none are on the upper side. They are said to vary from 1000 to 170,000 to the square inch."

From this it is evident that "plants have no general circulation (like that of animals, except the lowest) through a system of vessels opening into each other; but in them each living cell carries on a circulation of its own, at least when young and active. This may be beautifully seen in the transparent stems of chara and many other water plants, and in the leaves of the fresh water tape-grass (Vallisneria), under a good microscope. Here the sap circulates, often quite briskly in appearance (but the motion is magnified as well as the objects), in a steady stream, just beneath the wall, around each cell, passing up one side, across the end, down the other, and so round to complete the circuit, carrying with it small particles or the larger green grains which make the current more visible. The movement belongs to the *protoplasm* or jelly-like matter under the cell wall; as this substance has the same composition

as the flesh of animals, it is not so strange that it should exhibit animal-like characters.

"Although contained in cells with closed walls, nevertheless the fluids taken in by the roots are carried up through the stem to the leaves of the topmost bough of the tallest tree. What makes it ascend to the leaves?

"To anwer this question, we must look to the leaves and consider what is going on there. For (however it may be in the spring before the leaves are out), in a leafy plant or tree the sap is not forced up from below, but is drawn up from above. Water largely evaporates from the leaves; it flies off into the air as vapor, leaving behind all earthy and organic matters—these not being volatile—the sap in the cells of the leaf becomes denser, and draws upon the more watery contents of the cells of the stalk, these upon those of the stem below, and so on from cell to cell down to the root, causing a flow from the roots to the leaves which begins in the latter, just as a wind begins in the direction towards which it blows" (662).

The process of absorption and circulation we have here described, though simple in its nature and free from any complication of muscular action, like that existing in the systems of animals, is nevertheless wonderfully energetic. No animal offers the resistance to the elevation of fluid that plants present, yet the movement of their fluids is not more regular than that found in the loftiest plants. In such plants the principles of osmosis as presented by the root-tips, and actions of chemism in the leaves, suffice to carry on the difficult circulation. Surely the action of such potent forces should not be overlooked in investigating these phenomena in animals.

356. Absorption in Animals is three-fold in its nature. 1st, by veins or bloodvessels; 2d, by lymphatics; 3d, by the villi on the intestinal walls which deliver the fluid material or chyle into the lacteals. For the differences in character of the material absorbed in these three cases, we must refer to works on physiology. The point we desire to emphasize in connection therewith is this:

Whether the absorption by root-tip, bloodvessel, lymphatic, or villus, be osmotic or dialytic, it matters but little; so long as there are no chemical changes in medium or fluid both actions are molecular movements, the only difference being that in the one, movement occurs through sensible pores, and in the other, through physical pores or intermolecular spaces. The actions we witness in a capillary tube of sufficient diameter may be regarded as merely visible molar representations of what is taking place on the invisible molecular scale, both in osmosis through membranes and in dialysis. To so great an extent is

this true that many group all these phenomena together, and speak of them as phenomena of capillarity, including both visible or sensible and physical or molecular interstices under the term capillary.

357. Harvey's Mechanical Theory of the Circulation.—This explanation of the circulation of the blood was introduced by Dr. Harvey, more than two hundred and fifty years ago. It is based upon the existence, actions, and relations of the valves of the heart and veins. It conceives that the phenomena are purely mechanical, the heart driving the blood through the arteries to the capillaries into the veins, and so back through the veins to the heart.

By this theory the heart is supposed to act after the fashion of a simple force-pump, the only other force brought into play being the muscular and elastic coats of the vessels.

To account for the peculiarities in the capillary circulation, the action of nerves upon the muscular walls of the minute arteries is admitted by modern physiologists, but further than this the majority have been unwilling to go, and yet with this addition Harvey's explanation is by no means satisfactory when submitted to a careful and critical examination. It is good as far as it goes, but it does not meet all the circumstances even of the simplest condition of the case.

358. Insufficiency of the Simple Mechanical Theory of Circulation.—1st. The phenomena of transpiration (338, 4th) show that considerable force is required to drive the blood through such narrow channels as the capillaries, unless these vessels themselves assist the movement. In attempting to make minute injections after death, and when all traces of rigor mortis have passed away, the anatomist finds it very difficult to avoid rupture of the capillaries. The increase in resistance of minute vessels to the establishment of flow under pressure, is as the fourth power of their diameters. The significance of this is not recognized until a calculation is made for a given case.

2d. In plants the circulation is more extraordinary than in animals, yet they have no heart nor any substitute therefor. Neither do they have a nervous system to regulate contractions of the walls of their vessels. Osmosis in their cells and rootlets, and chemism in their leaves, suffice to overcome resistances amounting sometimes to more than fifteen atmospheres of pressure.

3d. In the lower types of animal creation there is often an energetic circulation without a heart. Even in insects, the highest of invertebrates, a dorsal vessel, as it is called, which

has but the feeblest muscular power, is frequently all the apology that can be found for a heart.

4th. The lowest of vertebrates, the lancelet or amphioxus, does not possess a heart. The only substitute for it is a large bloodvessel resembling the dorsal vessel of invertebrates.

5th. In fishes there is no systemic heart. Sluggish as their circulation is, it is hardly possible to imagine that their pulmonary heart drives the blood through both pulmonic and systemic capillaries against all the obstacles that two sets of transpiration resistances offer.

6th. Even after the heart is exsected, circulation is said to continue in the capillaries for a brief period of time.

7th. In instances where twin monsters have gone well on to full period, and one happens to be acardiac, yet otherwise well developed, there has been circulation without a heart.

8th. In the human adult the portal circulation is without a heart, yet during absorption of digested food into the general circulation it returns more fluid than it receives.

9th. In the kidney there is also a minute portal circulation between the vessels of the convoluted tubes and the Malpighian tufts. This has no propelling vessel like a heart attached to it.

10th. The flow in capillary vessels is often continuous and free from pulsation, sometimes it undergoes retrogression, passing backwards from arteries to veins. This is against the action of the heart.

11th. After death the arteries are practically empty. It is very difficult to conceive that the heart alone could produce any such results as this. If we admit that the capillaries have any action in carrying on the circulation, the explanation is then a very simple matter.

359. Draper's Physico-chemical Theory of Circulation.—To overcome the incompetency of the simple mechanical hypothesis to meet these objections, a theory based on molecular forces and chemism was advanced by my father, Prof. J. W. Draper, in his "Human Physiology," published in 1858. In this, the function of the heart in filling the great and small arteries is fully admitted, but it is confined to that duty. The chief seat of the circulatory force is located in the systemic, pulmonic, and other capillaries. Just as in plants, it originates in the changes taking place in the leaves.

In the systemic vessels there is a fluid containing cells charged with oxygen, and losing it to the surrounding parts, the conditions explained in (354) exist. Circulation of the contained fluid, he maintains, must, therefore, of necessity take place.

In the pulmonic circulation, the conditions are merely changed

or reversed; the prime cause in that case is affinity of the oxygen of the air cells for the hæmoglobin of the discs.

So also in the portal and renal double capillary circulations, the explanation is found in the chemical relations existing between the blood and the cells of the organ through which it is flowing.

It is interesting to note how those who will not admit this simple and all sufficient theory, so consonant with modern ideas, become involved in self-contradictions and obscurity. Take, for example, "Flint's Physiology," on page 294 of the volume on circulation, he says: "It is unphilosophical to invoke the aid of currents produced in capillary tubes in which liquids of different characters are brought in contact, or a 'capillary power' dependent upon a vital nutritive attraction between the tissues and the blood."

On page 219, he is compelled by the facts to uphold the very doctrine to which he objects on page 294, for he says: "The distention of the heart in asphyxia is, therefore, due to the fact that the *unaërated blood cannot circulate in the systemic capillaries.*" Why? Evidently because it has lost its normal affinity for the vessels and tissues, and, therefore, cannot move, since it now falls under the influence of the laws of transpiration.

So also in "Foster's Physiology," page 172, when speaking of the *stasis* preceding inflammation, he says: "It must, therefore, be due to some new and unusual resistance occurring in the capillary area itself. The increase of resistance is not caused by any change confined to the corpuscles themselves, for if after a temporary delay one set has managed to pass away from the inflamed area, the next set is subjected to the same delay. The cause of the resistance must, therefore, lie in the capillary walls, or in the tissues surrounding them, or, to speak more correctly, *it depends on a disturbance of the relations which in a healthy area subsist between the blood in the capillaries, on the one hand, and the capillary walls with the tissues of which they are a part, on the other.*"

While treating of the causes of circulation, no active part is assigned by Foster to the capillaries, beside that of being mere channels. When endeavoring to explain phenomena of inflammation, disturbance in the relations of the blood to the walls of the vessels is allowed, being unavoidable. Clearly the disturbance here admitted, acknowledges preëxisting local conditions, which carried on the circulation, but have been interfered with and placed in abeyance.

Verification of Prof. Draper's explanation of the circulation of the blood is to be found in the unavoidable admissions of those who oppose it. What better proof of its truth could be demanded?

360. The Physics of Respiration.—In (188) the mechanical portion of the respiratory act has been described. By it air is introduced as far as the smaller bronchi, just as in the circulation of the blood the mechanical force suffices to deliver blood to the capillary bloodvessels. At this point in both systems, the actions become physical, and belong to the province of molecular forces and motions.

Even in bronchi of moderate size, the principle of simple diffusion of gases (343) is resorted to, and an exchange accomplished between the oxygen of the atmosphere and the impure gas of the air cells. For the interchange of the gas of the cells with the carbonic acid gas in the blood, the principles of diffusion through barriers and of solution in fluid are brought into play. The union of oxygen with the hæmoglobin of the discs, we may regard as an action of chemism.

Returning to the lungs, the changes which take place consist in the elimination of carbonic acid gas, vapor of water, and other bodies. The stages here are the same as for the introduction of oxygen, but occur in reverse order. For a detailed description of these the student is referred to any modern textbook on physiology. Our purpose has been simply to show the direction in which the principles we have been studying are applied, and the necessity for some knowledge on the part of physicians regarding them.

SECTION V.

ACOUSTICS.

CHAPTER XI.

VIBRATIONS AND UNDULATIONS.

Definition and province of acoustics—Vibrations described—Relations of vibrations and undulations—Transverse vibrations—Longitudinal vibrations—Circular or elliptical vibration—Undulations and their graphic representation—Undulations in space—Undulations in tubes—Reflection of waves—Interference of waves.

361. Definition and Province of Acoustics.—The term is derived from a Greek word signifying to hear; it includes the study of sounds in all forms in which they are appreciable by the ear, and of vibrations in elastic bodies by which sound is produced.

Music treats of sound in relation to the pleasure it affords. Acoustics deals with the manner of production, propagation, perception, and comparison of sounds.

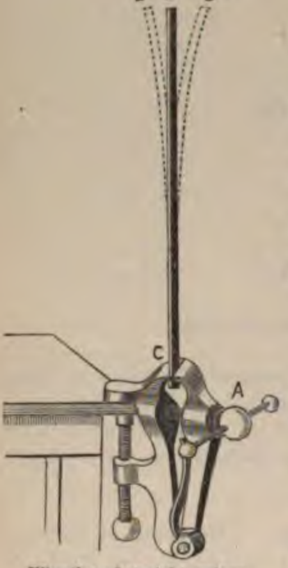
All sounds originate in impulse, or in vibrations of the particles of elastic bodies, which generally reach the ear through the medium of undulations in the air. We shall, therefore, in the first place inquire into the characters and varieties of vibrations and undulations.

362. Vibrations Described.—Vibrations may be defined as rapid movements of oscillation, similar in many respects to the movement of a pendulum (305).

It may be illustrated by the arrangement Fig. 144, in which one end, C, of a long steel spring is gripped in the jaws of a vice, A. The free end of the spring D is then drawn to one side to D′; on being released, its elasticity carries the free end back to D, but the kinetic energy it has gained in movement is so great that it passes on to D″ before it comes to rest.

Here potential energy being at the maximum, the free extremity is carried back to D, and by kinetic energy to D′, and so on. Each movement becomes less and less, as in the case of the pendulum, and finally ceases, its energy having been consumed in friction with the air.

Fig. 144.



Vibration of straight springs.

The movement of the extremity of the spring from D′ to D″ or from D″ to D′, is called a *single vibration* by the French. The English and Germans call a vibration the movement from D′ to D″ and back again to D′. The vibration of the French system is, therefore, a semi-vibration of the English system. The English, as compared with the French, is a double or complete vibration.

The time occupied in executing a complete vibration is called the *period* of vibration.

The *amplitude* of a vibration in any part of the spring, is the distance from the middle position to either of its extreme positions.

A moment's observation shows that while the amplitude of vibration for different parts of the spring is very variable, the period for each part is the same. In respect to isochronism the spring resembles the pendulum.

363. Relations of Vibrations and Undulations.—If one taps with the finger upon a surface of still water in a large vessel a wave-like or undulatory movement of the surface of the liquid is produced, which originating at the point where the finger touches passes outwards to the borders of the vessel. The tapping or vibrating movement appears to be distinct from the wave-like or undulatory motion; while the vibration is in a vertical, the undulation is in a horizontal plane. The molecules of the liquid seem to pass in the direction of the wave movement, yet this is not the case, as may be readily proved.

Place a cork or chip upon the surface of water in a pond; drop a pebble into the water at a distance of about five feet from the chip. The water at the point of impact is thrown into a vibratory motion as in the tapping experiment. Undulations originate at this point and pass in a succession of circles to the shore, where they break and are lost. As each wave

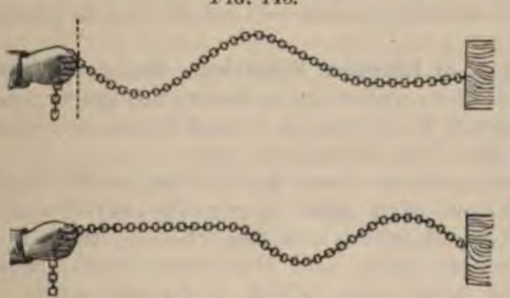
reaches the chip the latter is not driven forward, but simply rises and falls in a vertical plane. The chip can only move as the molecules of water move. Since it moves in a vertical plane, it follows that the actual movement of the water molecules is also in a vertical plane, exactly as it was in the vibration which originated the wave motion.

From the above facts, it is evident that the relations of vibrations and undulations are as follows: 1st. Undulations originate in a vibratory movement in a medium. The vibration is the cause, the undulation an effect. 2d. The passage of vibrations along the medium gives to the latter the wave-like or undulatory condition. 3d. While the vibratory movement is of very slight extent, the undulation may pass over considerable distances. 4th. In undulations it is the form only that advances, not the molecules or particles (130). *The undulation is translated motion, not translated matter.*

364. Transverse Vibrations.—Vibrations may take place in different ways. The first of these is where they are at right angles or vertical to the course of the waves. Such are called *transverse.* In waves on water they approach this character, though, as we shall see later on, they are much more complex than they at first appear to be (366).

A good illustration of transverse vibration is afforded by attaching *one end of a long chain to a suitable support*, and then holding it tolerably tense at the other. On moving the hand up

FIG. 145.



Transverse vibration.

and down, each link of the chain takes on the up and down movement imparted by the hand to the first link, and a wave-like motion passes along the chain to the attached end. A long cord or rubber tube filled with sand may be used; in each case the particles move transversely, only the wave form advances.

365. Longitudinal Vibrations.—In (303), transmission of a compression impulse along a rod was illustrated, and the manner

of transmission described by a series of suspended balls. As the action is along the length of the rod, or series of balls, it is called *longitudinal.* As we have longitudinal impulse, so we have longitudinal vibration, in which impulse after impulse is imparted to molecule after molecule of the rod, each molecule swaying backwards and forwards, but moving through an infinitely minute distance compared with that traversed by the wave.

The transmission of longitudinal vibration may be admirably imitated by means of the brass spiral. This consists of a brass wire, about one-fortieth of an inch in diameter, coiled in a close spiral one-half inch in diameter and thirty feet long. Fasten one end of the coil to a firm support, then holding it taut in the left hand, with the thumb and index finger of the right, nip the spiral about ten inches from the left hand, and draw that turn of the spiral towards the left hand. In this way the first sixty or one hundred turns of the spiral are drawn closer together or compressed. Suddenly releasing the spiral from the finger and thumb of the right hand, a wave-like movement of compression followed by relaxation passes along the spiral to the fixed extremity. In the passage of the wave each turn or coil of the spiral oscillates or vibrates forward and backwards through a very slight extent, but the wave form of compression and relaxation passes throughout the extent of the coil.

As in the spiral coil, we see a wave of compression and relaxation passing along the spiral, so in all longitudinal vibration a similar wave of compression and rarefaction is produced.

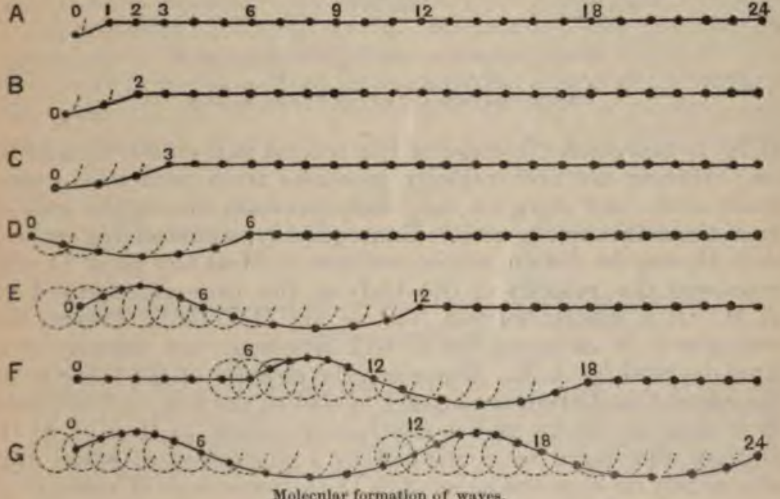
366. Circular or Elliptical Vibration.—Reference has been made to the fact, that in waves upon water, though movement of the particles appears to be simply up and down, it is quite complex. Regarding this, Prof. Weinhold says:

Careful experiments have shown that, when a uniform series of waves follow each other along the surface of water, the particles of liquid which are disturbed by them move in elliptical or circular paths, and that hence each particle returns again to the point from which it started, while the onward motion of the whole wave is due to the fact that each liquid particle commences its motion somewhat later than the preceding one.

Fig. 146 is intended to illustrate the formation of waves by the circular motion of individual particles of water. For sake of clearness, only a few particles are represented in the figure, those shown being so far apart that each one begins to move when the preceding one has completed the twelfth part of its circular motion; the portion of its path which each particle

has already described at the instant to which each figure corresponds is shown by the dotted curves. A represents the surface after the particle 0 has moved through one-twelfth of a circle; B after 0 has moved through two-twelfths and the particle 1 through one-twelfth of a circle. In C the particle 0 has passed through three-twelfths, or one-fourth of the circle; in D it has described a semi-circle; and in E it has returned to

FIG. 146.



Molecular formation of waves.

its original place. If only a single wave passes, each particle comes to rest after describing a circle. F represents the surface at the moment when the wave has moved onward through half its whole length further than it was in E; and if there are successive waves, each particle repeats its motion, as shown in G.

By means of the spiral coil all forms of vibration we have considered may be illustrated and undulations produced. In circular vibration, the hand is moved in a small circle; in elliptical, in an ellipse.

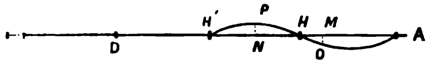
367. Undulations and their Graphic Representation.—Deschanel says: "An undulation may be defined as a system of movements in which several particles move to and fro, or round and round, about definite points, in such a manner as to produce continued onward transmission of a condition, or series of conditions."

The terms employed in connection with vibrations, as *amplitude*, etc., are also used in the case of waves. See 131, for wave measurements.

Undulations may be divided into three groups: 1st. Those produced by transverse vibrations; 2d. Those by longitudinal vibrations; and, 3d. Those by circular or elliptical vibrations. Each of these necessarily imparts special characters to the undulations it produces.

The graphic representation of undulations is thus briefly described by Ganot: Draw a line of indefinite length and mark off A H, Fig. 147, to represent the time of one half-vibration,

FIG. 147.



Graphic representation of velocity of oscillating body.

H H′ to represent the time of the second half-vibration, and so on. During the first, velocity increases from zero to a maximum at the half vibration, and then decreases during the second from the maximum to zero. Consequently, a curved line or arc, A O H, may be drawn, whose ordinate O M at any point O will represent the velocity of the body at the time represented by A M. If a similar curved line or arc H P H′ be drawn, the ordinate P N of any point P will represent the velocity at a time denoted by A N. But since the *direction* of the velocity in the second oscillation is contrary to that in the first, the ordinate N P must be drawn in the contrary direction to that of M O. If, then, the curve be continued by a succession of equal arcs alternately on opposite sides of A D, the variations of velocity of the vibrating body will be completely represented by the varying magnitudes of the ordinates of successive points of the curve.

368. Undulations in Space.—If we examine the circles of waves produced on water when a pebble is dropped therein, we find that the altitude of each circular wave, or the amplitude of vibration of its particles becomes less as we pass outwards from the centre or point of origin. This was to be expected as a necessary consequence of diffusion over a greater space of the energy which originated them.

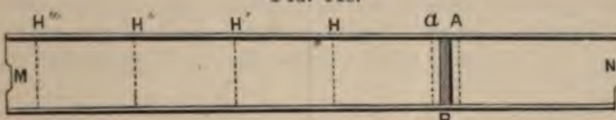
What we see taking place on the surface of water is an indication of what occurs in the case of undulations in air. In the latter instance, since movement is equally free in all directions, the waves pass out from the centre of disturbance as spheres of compression, produced in the manner described under longitudinal vibration (365). Hence the energy initiating them is of necessity rapidly diffused over the ever-increasing space, and the amplitude of vibration of the particles steadily diminished.

The power of air to transmit impulse, and also diminution of the violence of the same, with increased distance from the

point of origin, were well shown by the explosion of five tons of gunpowder in Regent's Park, London, in 1874. The walls of houses were seriously damaged at a distance of four hundred yards. Windows, doors, and ceilings were broken at six hundred yards. Concussion was distinctly felt at two miles, and the sound reached Waltham, fifteen miles away.

369. Undulations in Tubes.—In the propagation of undulations in tubes, the loss is not so rapid as in open space. This may be easily demonstrated by producing waves in a long open trough of water the sides of which are vertical, smooth, and not very far apart; under these conditions the waves preserve their altitude with very little diminution throughout the length of the trough. To make the manner of propagation as clear as possible, suppose that M N, Fig. 148, represents a tube filled with air, and

FIG. 148.



Sound undulations in tubes.

P a piston oscillating therein. When the piston moves from A to *a*, the air in the tube is condensed. By virtue of its elasticity it is not compressed throughout its whole length at once, but only within the distance A H. This is called the condensed wave.

Imagine the tube to be divided into lengths equal to A H, and each of these into layers parallel to the face of the piston. When the first layer of A H ceases to move the first layer of the second wave H H′ moves, and so on through the layers of the remaining divisions or waves. The compressed wave thus advances, its parts moving in succession with equal velocity and condensation.

By return of the piston in the direction *a* A, a vacuum is produced, and the layer in contact with its face is rarefied. As was the case with the condensed wave, a rarefied wave passes along the tube of the same length as the condensed wave, and immediately following it.

The condensed and expanded wave, taken together, form a complete undulation. As the vibrations are more rapid the undulations are shorter.

During transmission of undulations through a medium, any two particles are in the same *phase* when they move with like velocities in similar directions. When they move with equal velocities in opposite directions they are said to be in

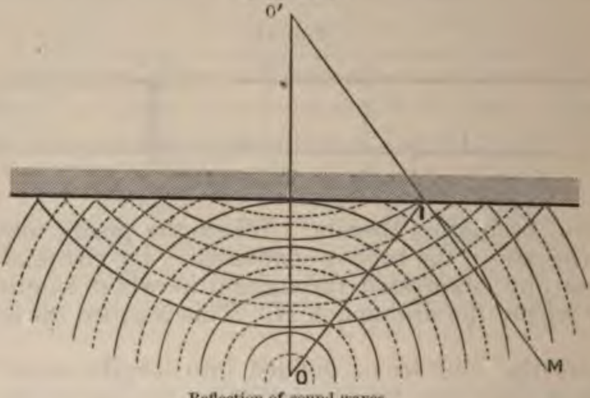
opposite phases. Separation by a whole wave length produces motions in the same phase; separation by half a wave length produces phases in opposite directions.

In transmission of waves along a tube, there is not the same loss as in the case of spherical waves, since the force or energy is confined within equal limits and not allowed to diffuse itself over a great extent of space.

370. Reflection of Waves.—When circular waves on the surface of water meet a resisting medium which presents a plane surface, the undulations undergo reflection according to the law of reflection (304), and pass backwards from the reflecting surface.

Let a system of water waves originate at O, Fig. 149, their

FIG. 149.



Reflection of sound waves.

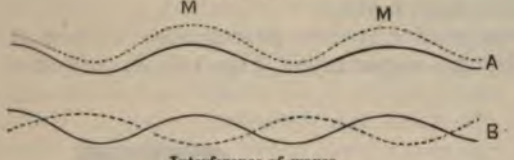
crests and depressions being represented by the full and dotted circles. On meeting the plane surface they are reflected in the manner indicated, the second system of circles having their centre at O′, the same distance from the plane surface as O, but on the opposite side. An observer placed at M will refer the wave reflected from I, to O′ as its point of origin.

371. Interference of Waves.—Suppose two equal systems of water waves, Fig. 150, A, one represented by the continuous and the other by dotted lines. When they meet at M with crests corresponding to crests, and troughs to troughs, the wave height of the combined system will be increased, as at M M.

If, on the contrary, the waves meet, or interfere as delineated at B, the crests of the dotted system fitting into the troughs of the other system, they will mutually destroy each other and smooth water will result.

In the experiment described in the preceding article, where a system of circular waves is reflected from a plane surface, the effects of interference are well illustrated. As the incident and reflected systems meet, every variety of conditions arise. In

Fig. 150.



Interference of waves.

some positions the waves are seen surmounting each other and producing increased wave height; in others neutralizing and restoring the original level of the water. In the approach of a steamboat to her dock, these interferences of wave systems may be seen to perfection, as the waves from the paddle-wheel undergo reflection from the sides of the pier.

CHAPTER XII.

GENERAL PROPERTIES OF SOUND.

Noise and sound—Origin of sound—Sounds from inanimate nature—Propagation of sound—Manner of propagation of sound—Dissipation of sound—Conduction of sound—The stethoscope and auscultation—Velocity of sound in gases—Velocity of sound in liquids—Velocity of sound in solids—Reflection of sound from plane surfaces—Reflection of sound from curved surfaces—Refraction of sound—Polarization of sound.

372. Noise and Sound.—It is not easy to draw a sharp line of distinction between noise and sound. We may, however, say that by noise we understand either brief vibration, or impulse, like the discharge of a cannon; or a mixture of discordant sounds, like the passage of a carriage, the rolling of thunder.

A true sound, or a musical sound, on the contrary, is more or less sustained and continued, and euphonious or well-sounding. Its valuation or rate of vibration is fixed and uniform, and easily determined.

373. Origin of Sound.—In (361) it is stated that all sounds originate in impulse, or in vibrations of the particles of elastic bodies. Of this we offer proof.

Vibrations may be caused either by shock, or by friction, as with the bow of a violin or the tremulous movements of reeds (393). Any substance which may be made to produce sound is called a sonorous body.

The existence of vibration during the emission of sound may be shown by the experiment, Fig. 151, in which a bell jar is

FIG. 151.

Vibration and sound.

held horizontally in the manner indicated, and struck with a small wooden mallet. If while still sounding a little piece of metal is tossed into the interior, it is thrown into rapid motion by oscillations of the jar. Placing the hand upon the jar these may be felt, though contact causes them to cease.

In illustration of vibration by the spring and vice, Fig. 144, while the spring projects for a considerable distance vibrations are perceptible to the eye, and a low humming sound is produced. On lowering the spring in the vice, as it becomes shorter the rate of oscillation grows more rapid, and the sound more shrill. At last, when a very short portion of the spring projects, the movements are so small in extent, and brief in duration, that the eye fails to perceive them, though they can still be detected by the ear and sense of touch.

In the course of the above experiment, since sounds of many degrees have been obtained, and in every case attended by vibration, we conclude that all sounds take their origin in oscillations of the molecules of bodies.

374. Sounds from Inanimate Nature.—Setting aside the crash and rolling of thunder, the rumble of an earthquake, the explosive discharge of volcanoes, the splashing and roar of water, it may be said that the sounds produced by inanimate nature take their origin in the movements of winds. These often throw various objects into vibratory movement. All who live in the vicinity of telegraph wires in exposed positions, and have heard the sound produced therein, have had frequent opportunities of verifying this statement. The infinite variety of sounds evoked

in a forest during a storm arise from the vibrations which wind has produced in the leaves, twigs, stems, and shafts of trees.

A pleasant application of wind to evoke sonorous vibrations is made in the Æolian harp. This consists of a long box of thin wood, on the upper surface of which violin strings are stretched. Excepting one, which is heavier than the rest, they are tuned in unison; when placed in a window where currents of wind may pass over its strings they are thrown into vibration. "After a pause a low solemn note is heard, like the bass of distant music in the sky; the sound then swells as if coming near, and other tones break forth, mingling with the first and with each other. In the combined and varying strain, sometimes one clear note predominates and again another, as if single musicians alternately led the band; and the concert seems to approach and recede, until with the unequal breeze it dies away, and all is hushed."

A strong current of air passing through chinks in walls, cracks in doors, or through keyholes, originates sounds which rise and fall as the force of the moving air varies. Thus the deep howlings which issue from capacious chimneys of ancient houses take their origin.

Not only do sounds originate by the action of winds, but such impalpable agents as light can also be made to initiate sound vibrations. In following up the experiments which led to the discovery of the photophone (437 A) Prof. Bell says: "In my Boston paper the discovery was announced that thin disks of very many different substances *emitted sounds* when exposed to the action of a rapidly interrupted beam of sunlight. The great variety of material used in these experiments led me to believe that sonorousness under such circumstances would be found to be a general property of all matter."

"At that time we had failed to obtain audible effects from masses of the various substances which became sonorous in the conditions of thin diaphragms, but this failure was explained upon the supposition that the molecular disturbance produced by light was chiefly a surface action, and that under the circumstances of the experiments the vibration had to be transmitted through the mass of the substance in order to affect the ear. It was, therefore, supposed that, if we could lead to the ear air that was directly in contact with the illuminated surface, louder sounds might be obtained, and solid masses be found to be as sonorous as thin diaphragms. The first experiments made to verify this hypothesis pointed towards success. A beam of sunlight was focussed into one end of an open tube, the ear being placed at the other end. Upon interrupting the beam, a clear, musical tone was heard, the pitch of which depended upon the

frequency of the interruption of the light, and the loudness upon the material composing the tube."

"In order to study these effects under better circumstances the materials were enclosed in a conical cavity, B, in a piece of brass closed by a flat plate of glass. A brass tube leading into the cavity served for connection with the hearing-tube A. When this conical cavity was stuffed with worsted or other fibrous materials the sounds produced were much louder than when a tube was employed."

Fig. 152.

Intermittent beam of light develops sound.

"Upon smoking the interior of the conical cavity, and then exposing it to the intermittent beam, with the glass lid in position, the effect was perfectly startling. The sound was so loud as to be actually painful to an ear placed closely against the end of the hearing-tube."

"In regard to the sensitive materials that can be employed, our experiments indicate that in the case of solids the physical condition and the color markedly influence the intensity of the sonorous effects. *The loudest sounds are produced from substances in a loose, porous, spongy condition, and from those that have the darkest or most absorbent colors.*"

"The materials from which the best effects have been obtained are cotton-wool, worsted, fibrous materials generally, cork, sponge, platinum and other metals in a spongy condition, and lampblack."

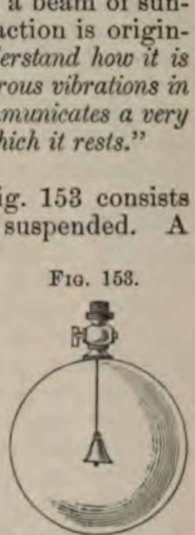
"The loud sounds produced from such substances may, perhaps, be explained in the following manner: Let us consider, for example, lampblack—a substance which becomes heated by exposure to rays of all refrangibility. I look upon a mass of this substance as a sort of sponge, with its pores filled with air instead of water. When a beam of sunlight falls upon this mass, the particles are heated, and consequently expand, causing a contraction of the air-spaces and pores among them. Under these circumstances a pulse of air should be expelled, just as we would squeeze out water from a sponge."

"The force with which the air is expelled is greatly increased by the expansion of the air itself, due to contact with the heated particles of lampblack. When light is cut off, the reverse takes place. The lampblack particles cool and contract, thus enlarging the spaces between them, and the enclosed air also becomes cool. Under these circumstances a partial vacuum is formed among the particles, and the outside air reabsorbed, as water is by a sponge when the pressure of the hand is removed."

"I imagine that in some such manner as this a wave of condensation is started in the atmosphere each time a beam of sunlight falls upon lampblack, and a wave of rarefaction is originated when the light is cut off. *We can thus understand how it is that a substance like lampblack produces intense sonorous vibrations in the surrounding air, while at the same time it communicates a very feeble vibration to the diaphragm or solid bed upon which it rests.*"

375. Propagation of Sound.—The apparatus Fig. 153 consists of a glass globe; in the interior a small bell is suspended. A stopcock closes the aperture, and by means of the screw it may be attached to an air-pump and exhausted.

FIG. 153.



Propagation of sound, bell in vacuo.

Commencing the experiment with the globe in an exhausted condition, if the vacuum is nearly perfect, scarcely any sound can be perceived no matter how violently we ring the bell. What little sound we do hear passes along the suspending rod to the metallic cap. If this has been made of poor conducting material, no noise whatever is heard. Therefore, sound cannot pass through a vacuum.

Admitting air to the sphere and keeping the bell in motion, we soon begin to hear its ring, which, as air enters, becomes louder and louder, reaching its maximum when the interior and exterior pressures are equal. We consequently conclude that sound is propagated through air. We would add that, as a rule, it always reaches the ear through this medium.

Again exhausting the sphere, and filling it in succession with various gases, we find that while they all permit conduction of sound from the bell, they differ greatly in ability to do so. Hydrogen, for example, transmits a feeble sound, while denser gases, according to their increase in specific gravity, transmit louder sounds. Increase in pressure also favors passage of sound through any gas.

In like manner, sound is propagated through water and other liquids, and also through all elastic solids. Evidence of this will be given when we treat of the velocity of sound through various media.

"Peschel states that the greatest known distance to which sound has been carried through the atmosphere is 345 miles, as it is asserted that the very violent explosions of the volcano of St. Vincent have been heard at Demerara. There is no doubt that sound travels to a greater distance and more loudly through the earth's surface than the air. Thus, in the wilds of Africa, the roar of a lion is heard for many miles around. This is owing to the animal placing its nostrils within a short distance

of the ground, and the transmission of the sound by the surface. It is stated on good authority that the cannonading at the battle of Jena, in 1806, was heard, though but feebly, in the open fields near Dresden, a distance of ninety-two miles; while in the casemates of the fortifications (underground) it was heard with great distinctness. So it is said that the cannonading of the citadel of Antwerp, in 1832, was heard in the mines of Saxony at a distance of 370 miles."

376. Manner of Propagation of Sound.—In the discussion of the relations of vibrations and undulations (363), it was stated that vibrations produce undulations. Vibrations of a sonorous body originate sound waves, or undulations in the air, in which the molecules of air are thrown into longitudinal vibrations, just as an oscillating piston produces undulations in a tube (369).

Vibrations in a sonorous body may be either transverse, as in a string, or longitudinal, as in a rod; but in their passage through air as a conducting medium, they of necessity become longitudinal; as Dr. Arnott puts it: "There is no cohesion to link the air-particles together, so *lateral* motions of any one particle would not be passed on to the next, only *forward* impulses, impacts, or pushes, can be communicated." Herein we find an illustration of the necessity of drawing a distinction between vibrations in a sonorous body, and those in the medium the sound traverses.

Of the passage of sound in air, Weinhold says: The motion of the particles of air during propagation of sound resembles to some extent that of the particles of water during the translation of a wave; hence, sound is said to be conveyed by an undulatory or wave-like motion in air.

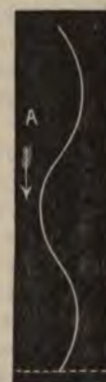
The resemblance is, however, confined to the fact that each particle performs the same definite movement, but commences its motion somewhat later than the preceding one. The path described by each is essentially different in the two cases. When a wave is propagated through water, each particle describes a circle (366); when sound is propagated through air, the molecules move in a straight line, backwards and forwards, in the direction the sound is propagated.

A wave on water is formed by a series of crests and hollows (or elevations and depressions); a wave of sound, by a series of alternating compressions and rarefactions of air. Such compressions and rarefactions of air take place whenever a body, surrounded by air, is set in rapid vibration—that is, when its parts are made to move rapidly to and fro through a short space. Suppose a tuning-fork is struck, and, for sake of simplicity, that one of its prongs vibrates exactly in a direction towards and away from us. As soon as the prong begins to move towards us, the nearest particles of air are compressed,

le those further away are unaffected by the impulse in conse-nce of their inertia. Before the prong begins its backward ion, the compressed particles of air expand again, and the ansion takes place in whatever direction they meet least stance.

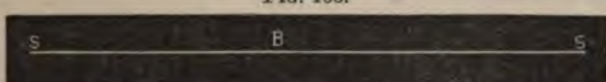
The tuning-fork does not perform merely a single vibration, the movements are uniformly repeated, and a series ondensations and rarefactions follow each other in d succession, and are propagated to the ear; the portion of air close to the ear vibrates to and fro, :tly like that close to the prong of the fork, only :tle later."

FIG. 154.



he motion of the particles of air during the pro-ation of sound may be further demonstrated with help of Figs. 154 and 155. A narrow slit, S S, is out of a piece of stiff paper (Fig. 155), which is er black, or at any rate of a dark color; this slip aper is then placed upon Fig. 154, so that the slit xactly along the dotted line. A is now slowly vn along in the direction of the arrow, the piece paper being held in the same position. At first lower extremity of the curved line Fig. 154 is

FIG. 155.



ı through the slit; but as A is drawn along, portions to right, and to the left, come successively in view; the small te dot, which is the only visible portion of the curved line,

FIG. 156.

Movement of molecules in propagation of sound.

appears as a point which moves first to the right and then to the left, and imitates closely the motion of a vibrating particle of air, the rate being, however, much slower. If now the slit be placed over the dotted line Fig. 156, and the slip C drawn along underneath it in the direction of the arrow, a representation is obtained of the motion of a series of particles of air which are acted on by a number of successive equal undulations or waves. Each particle merely moves a little right and left, and always comes back to its starting point; but the condensations and rarefactions, represented by the lines being respectively closer together or further apart, are gradually transmitted through the whole series from one end to the other.

377. Dissipation of Sound.—When sound passes out into space in what may be called the radiant form, as where the sonorous body is vibrating freely in air, it is evident from (368), that by diffusion of the energy producing the undulations, the sound must ultimately diminish and finally be lost.

The theoretical rate at which the loudness of a sound should change under these conditions, is inversely as the squares of the distances. According to Deschanel, this assumption is not strictly true, inasmuch as vibration implies friction, and friction implies generation of heat at the expense of the energy which produces vibrations. Sonorous energy must, therefore, diminish with distance somewhat more rapidly than according to the law of inverse squares. All sound, in becoming extinct, is converted into heat.

378. Conduction of Sound.—If in place of creating sound in open space it is produced in a cylindrical tube filled with air, as described in (369), the rate of loss is greatly reduced. The sonorous waves are no longer propagated as concentric spheres, but are reflected from the walls of the tube, and their intensity being thereby conserved, they may be conveyed to great distances.

In the experiments of Biot with the Paris water pipes, it was found that conversation in a very low tone could be carried on through a pipe 1040 yards long. Roughness in the sides of a tube diminishes its ability to convey sound. A very useful application of this property of air tubes to prevent dissipation of sound and carry it to a distance is seen in the speaking tubes generally introduced into dwellings. In these it is not only conveyed, but made to traverse curves and angles.

Sounds may also be conducted along such narrow channels as cords. An example of this is offered by the toy telephone or lover's telegraph, in which a string a hundred or more yards in length is attached to the bottom of a couple of small boxes of

wood or tin; these act as sounding boards, and are held at the full distance of the string from each other, with the cord taut. If a person speaks or whispers into one box, the vibrations pass along the string to the other box, and can be easily heard by applying the ear thereto. Fine metallic wires are substituted for string, with excellent results.

Along rods of wood sound waves pass with facility. Of this we have an example in the passage of sound along a billiard cue when one end is applied to the ear and the other scratched by a pin or touched to a musical box in action.

The wonderful facility with which sound passes along wooden rods received an admirable illustration some years ago in an exhibition called the Magical Orchestra. On the stage appeared a set of stringed instruments each supported by a slender wooden rod. The other extremity of the rod communicated with a similar instrument in a room beneath. When the performance began the musicians operated upon the instruments in the room below, the vibrations from these passed along the rods to the visible instruments, and the music was produced before the audience, the performers being invisible.

The vibrations in any rod along which sound is passing may be distinctly felt on touching it with the tip of the finger, but they are stopped at the moment of contact. It is on this principle that the dampers of pianos and other musical instruments act. Other bodies as wool, hair, feathers, leather, paper, or anything which does not, or is not in condition to conduct sound, will destroy it if they touch a vibrating body.

Among other solids, earth and stone also allow the propagation of sound through their mass even better than it can pass through air. So the savage detects the vicinity of his prey or enemy by applying his ear to the earth. In the transmission of sounds along the stone and brick of walls and beams of floors of houses we often find the explanation of singular and otherwise unaccountable noises which superstition has attributed to supernatural causes.

379. The Stethoscope and Auscultation.—Practical application of the difference in the conduction of sounds by solid, liquid, and gas, is made in medicine for the detection of changes which have taken place in the lungs and other organs. To this method of physical examination the name "auscultation" is given.

Auscultation consists in the direct application of the ear to the chest, or other part in which sound is to be detected; or the intervention between the ear and chest of an instrument called the stethoscope.

The earlier or Laennec stethoscope was a wooden cylinder perforated through its axis and enlarged at its extremities. It

possessed a certain advantage over direct application of the ear to the chest, in that vibrations were collected from a smaller area, and sounds heard could be located to greater advantage. To this, various forms of flexible stethoscope have succeeded. Some are double, the ear piece being arranged to have both ears brought into use at the same time.

In Fig. 157 an improved form of this instrument, contrived by König, is represented. It consists of a hollow metallic

Fig. 157.

Stethoscope.

hemisphere, the mouth of which is closed by two disks of rubber or membrane A C. By means of a stopcock the space between the membranes may be inflated with air or other gas, and a double convex lens formed. To the metallic hemisphere a number of tubulures with elastic tubes are fitted, enabling several persons to make observations at the same time. The outer membrane of the mouth is applied to the chest in the usual manner, when the sounds of the heart and lungs pass into the cavity between C and A, and thence by the tube to the ear.

By auscultation, physicians detect new sounds that have appeared in the various organs in the thoracic or other cavities of the body of which a brief account is given in (397), and also sounds produced in the abdomen by the beating of the fœtal heart.

In addition to the râles, rhonchi, etc., referred to above, auscultation enables us to detect changes in structure which attend consolidation of the lung by fibrinous and cellular material. We have seen in the study of the propagation and conduction of sound (375, 378), that, as a rule, solids are better conductors of sound than gases. In health the cells of the lung are filled with air, and by causing a person to speak while one's ear is placed on the chest-wall, the sound of the voice is transmitted in a muffled manner through the bronchial tubes and air-cells. When the lung is consolidated by pneumonic or phthisical deposits, sound is conveyed better from the larynx and tubes. The voice, therefore, is louder, as though the person was speaking immediately under our ear, in his chest; at the same time

its character is greatly changed, it becomes unpleasant and endowed with a nasal twang.

When fluid is poured into the cavity of the pleura from that membrane, the action is different to that described above. In this case the effusion presses the lung away from the chest-wall, the air-cells and smaller bronchi are closed, and all natural respiratory sounds are lost; even the intensity of the voice is reduced, since sonorous vibrations are not readily communicated from gas to fluid. Sometimes, just along the edge which marks the surface of the fluid, and where the lung is consolidated by its pressure, the effects of compression described above are produced, but they are limited in extent.

380. Velocity of Sound in Gases.—A sound produced near at hand appears to reach the ear instantly, but this is not the case in reality. We know that the lightning flash has caused the thunder, but we may not hear the latter for some seconds after the flash has vanished. Sound, therefore, requires time for its passage through air. This we might have foretold from the manner of propagation from molecule to molecule, one taking up the vibration a little later than the other.

Among the best experimental determinations of the velocity of sound are those of Moll and Van Beck, made by firing cannon on two hill-tops about eleven miles distant from each other, and noting the time between the flash and report. The average result of these was 1093 feet or 333 metres per second, at a temperature of 0° C., and a pressure of 760 m. Estimates varying slightly from this are given. They are due to the different conditions of the layers of air through which the sound passed.

The effect of temperature on the velocity of sound is shown by the experiments of Kendall in his North Pole Expedition, in which the rate was reduced to 314 metres per second, at a temperature of —40°. The increase in rate above 0° C. is about two feet per second for each degree centigrade. In England the estimate at 60° F. is 1120 feet per second.

The average velocity at ordinary temperatures may be taken at 340 metres per second. Since an English mile is about 1609 metres, sound requires about $4\frac{3}{4}$ seconds to traverse that space. From these data we may easily compute the distance of a cannon, by taking the time between flash and report. A lightning flash with its attendant thunder also gives means for estimating the remoteness of a cloud or storm. An interval of half a minute, in this case, indicates that it is a little more than six miles away. The computation of time and space may be made by the pulse, each beat being equal very nearly to $\frac{1}{6}$ of a mile.

The fact, that when an air is played by a band at a distance, we hear all the notes in their proper relation of time to each other, indicates that *all sounds travel the air with equal velocities.* While this may be true for sounds of equal strength, it is not the case when they differ greatly, for a violent sound is then found to have a greater velocity than a feebler one. Illustration of this was offered by artillery practice during the Arctic Expedition of Captain Parry, in which persons stationed at a considerable distance heard the report of the gun before they heard the order of the officer in command. In blasting operations, Mallett found that the larger the charge of powder, the louder the report, and the greater the velocity of transmission. With 2000 pounds of powder the velocity, according to his estimate, was 967 feet per second; with 12,000 pounds, 1210 feet per second.

As regards transit in altitude, Bravais and Martins found that sound moved at the same rate from the summit to the base of the Faulkorn, as from base to summit.

The following table gives the results of Regnault's experiments on the velocity of sound in different gases, through a tube 2000 metres in length:

	Metres per second.	Feet per second.
Air	333.00	1093
Oxygen	317.17	1040
Hydrogen	1269.50	4166
Carbon dioxide	261.60	856
Carbon monoxide	337.40	1107
Protoxide of nitrogen	261.90	859
Olefiant gas	314.00	1030

The velocity of sound is less in damp air; the loudness is also less. Dry frosty air is favorable to the transmission of sound. In country regions farmers often predict a change in weather by the manner in which the ringing of distant church bells is conveyed through the atmosphere.

According to Peschel sounds may be heard at the following distances in yards:

	Yards.
Musket report	8000
Marching company of soldiers	600 to 800
Squadron of cavalry at foot pace	750
Squadron of cavalry at gallop	1080
Heavy artillery at foot pace	660
Heavy artillery at gallop	1000
Strong human voice	230

381. Velocity of Sound in Liquids.—The velocity of sound in liquids was determined by Colladon and Sturm, in the Lake of Geneva. A bell was struck under water by means of a string, which at the same moment ignited powder. The observer was stationed at a distance with an ear trumpet, the mouth of which

was covered by membrane and placed under water. The time being measured between appearance of the flash and hearing the stroke on the bell, the velocity of transmission of the sound was obtained. At a rough estimate, it was four times the rate through air. The velocity of sound in different liquids, as determined by Wertheim, is as follows:

	Metres per second.
Ether	1159
Essence of turpentine	1265
Water	1437
Sea water	1455
Mercury	1471
Nitric acid	1521
Aqua ammonia	1820

The effect of temperature is shown by the following, from Ganot:

	Temp	Feet per second.
River-water (Seine)	13° C.	4714
River-water (Seine)	30° C.	5013

382. Velocity of Sound in Solids.—Many solids transmit sound better than either water or air. The rate in some is, however, less than the rate in air. The following table in feet per second is from Ganot:

Caoutchouc	197	Oak	12,622
Wax	2,394	Ash	13,314
Lead	4,030	Elm	13,516
Gold	5,717	Fir	15,218
Silver	8,553	Steel wire	15,470
Pine	10,900	Aspen	16,677
Copper	11,666	Iron	16,822

In wood, velocity is greatest with the grain.

Mallett gives the following results of his experiments:

	Feet per second
Wet sand	825
Stratified quartz and slate	1088
Discontinuous granite	1306
Solid granite	1664

The experiments of Genl. H. L. Abbot, in connection with mining operations at Hallet's Point, in which 50,000 pounds of dynamite were fired at a single explosion, and other experiments made since that time, give far higher velocities for the passage of waves through the earth, and show that the problem is a very complex one, the results being influenced by a number of conditions. Among these are the character of the explosive, and the power used in examining the tremor waves on the surface of the mercury of the *seismometer*. In an article on this sub-

ject in the "Am. Journal of Sciences and Arts," vol. xv. page 181, he says: "The velocities observed, all tend to confirm the idea that a slow-burning explosive, like gunpowder, generates a series of gradually increasing tremors, which, at a distance of a mile, are at first quite invisible with a less sensitive seismometer; and are only detected by it when near their maximum intensity. If Lieut. Leach's estimate of time for the arrival of the maximum wave be accepted, we have, therefore, for the first mile"—

Magnification.	Feet per second.
Power of 12 gives	8415
Power of 6 gives	5559
Minimum power gives	1240

383. Reflection of Sound from Plane Surfaces.—Where a system of sound undulations meets a barrier which presents a plane surface, the waves undergo reflection according to the principles laid down in (370). Thus, *echo* is produced in large rooms, and if the positions of the walls are in proper relation to the speaker, repetitions of the words uttered may be so frequent as seriously to impair their acoustic properties. At the villa Simonetta, near Milan, a pistol report is sometimes repeated fifty times, and at Pavia a building has been constructed in which the last syllable of a question is answered or echoed thirty times. Anything which presents broken surfaces diminishes the echo. It is, for example, less in a room filled with an audience than when empty. Curtains and hangings of all descriptions cause a diminution in the number of repetitions.

Reflection of sound waves or echo also takes place in the open air; especially is this noted along rivers with precipitous banks. The discharge of a gun, or explosion of a blast in quarrying rock, will often be repeated many times, taking on the character of rolling thunder.

In treating of the conduction of sound along speaking-tubes, we have referred to the reflection of the vibrations from the walls of a tube. After their direction has been changed they tend to advance in the new direct course, and not to spread out as when radiating from the point of origin. Upon this principle the speaking-trumpet depends for its action; the sound is thus directed by the speaker to whatever point he may desire with far less loss from lateral diffusion than if it were not employed.

Sounds are also reflected from such impalpable surfaces as clouds; of this we have an example in the reverberations of thunder. When the lightning flash is unbroken, and free from the zig-zag form, it is frequently attended by rolling thunder, the echoing reports being partly the results of reflections from the clouds.

384. Reflection of Sound from Curved Surfaces.—In the study of motion (304), and undulations (370), we have seen that reflection takes place on the opposite side of the normal or perpendicular, drawn to the point of impact of the incident molecule or wave; that the angle of reflection is equal to the angle of incidence; and both lie in the same plane.

Since any curved surface may be conceived to consist of an infinite number of plane surfaces, the law also applies in this case, and if the curvature is of proper shape, the inclinations of the plane surfaces forming it may cause the convergence of the sound waves. For a full explanation the student is referred to (481).

Illustration of the reflection of sound waves from curved surfaces is offered by means of the parabolic or conjugate mirrors used in experimenting with light and heat. If a watch is placed at the focus of one of the mirrors, the ticking sound it emits will be reflected in parallel lines, Fig. 158. Falling on

FIG. 158.

Sound in conjugate mirror.

the opposite mirror, the undulations are again reflected, and converged to the focus. A tube placed at this point will convey them to the ear, as indicated in the figure.

If sound is produced at the centre of a sphere, it is reflected back with wonderful intensity to the same point, constituting a powerful echo. If produced at one side of a circular space

under a hemisphere, a similar though less marked result is obtained. The circular gallery under the dome of St. Paul's Cathedral, in London, affords so good an illustration of this fact, that it is known as the whispering gallery. By whispering close to the wall on opposite sides of this space, two persons may readily carry on a conversation with each other. In like manner in rooms of an oval form, two individuals may converse in a whisper by standing at the foci, while those at a short distance from them are unable to hear their conversation.

Dr. Arnold relates: "It happened on board a ship sailing south in the Atlantic, towards Rio de Janeiro, while out of sight of land, that one day, persons on the deck, when near a particular part of it, thought they heard distinctly the sound of bells. All were attracted to listen, and the phenomenon was mysterious. Weeks afterwards it was ascertained that, at the time of observation, the bells of the city of St. Salvador, on the Brazilian coast, had been ringing on the occasion of a festival; their sound, therefore, favored by the wind at the time, had travelled over at least 100 miles of smooth water, and had been condensed by the concave sail to a focus on the deck of the vessel where it was listened to. In remote country places there is reason to believe that the reflection of distant sounds from the walls of lonely and uninhabited houses has sometimes led to the report that they were haunted."

Practical applications of the phenomena with which we have been dealing are found in the external ears or conchs of men and animals. These are constructed of cartilage covered internally by smooth skin, with the curvatures arranged to reflect sound undulations into the auditory canal. The ear-trumpet also acts on the same principle, collecting a great extent of waves by the expanded lip of its mouth, and reflecting them down the tube to the narrow exit, which is applied to the auditory canal of the ear of the person using it. The flexible stethoscope acts in part in the same manner.

The speaking-trumpet is another example. Peschel states, that the voice of a strong man sent through a trumpet eighteen to twenty-four feet in length, has been heard at a distance of three miles.

385. Refraction of Sound.—The experimental illustration of refraction and of its laws is best attained in the case of light (492). Sound undulations follow the same laws of refraction as do those of light. This was demonstrated by Sondhauss, who took a large spherical collodion balloon, and cutting segments a foot in diameter therefrom, fitted them to a circular ring. A double convex lens (528), a foot in diameter and four inches thick in the axis, was thus formed. On filling this with carbonic

acid gas, and placing a watch at a distance of a couple of feet in the axial line, its ticking could be found in the same line on the opposite side of the lens, at a proper position. This could only occur by a refraction of the sound in the same manner that light and heat are refracted.

The India-rubber balloons used as children's toys, if inflated with carbonic acid gas produce a similar result; if with hydrogen, they cause a dissipation of the sound, acting as a concave instead of a convex lens.

385 A. Polarization of Sound.—In the "Journal of the Franklin Institute," for 1881, Professor S. W. Robinson describes a series of experiments which tend to show that by means of suitable arrangements sound waves present phenomena of polarization resembling those offered by light. The apparatus employed consisted of polarizer and analyzer formed of tubes of a peculiar shape filled with coal-gas.

CHAPTER XIII.

SONOROUS BODIES.

Vibrating strings—Laws of transverse vibrations—Nodes and loops—Vibrating rods—Vibrating plates and bells—Vibrating membranes—Vibrating columns of air—Reed instruments—Singing flames—Sympathetic vibrations—Sensitive flames—Production of abnormal sounds in the chest.

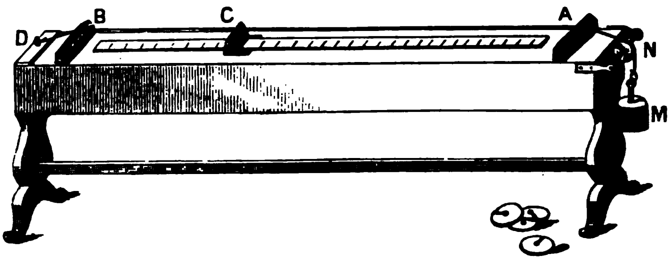
386. Vibrating Strings.—The term is applied both to the tense catgut cords and the wires used in the construction of pianos and violins. Stretched cords or strings may show either transverse or longitudinal vibrations. In practice only the former are used. The string is sometimes thrown into motion by plucking, or pulling it to one side, and then letting it free suddenly, as in the harp; again by a bow the threads of which are coated with resin, as in the case of the violin; or by a quick sharp blow, as in a piano.

Transverse vibrations may be illustrated to advantage by stretching a white cord in front of a dead-black surface. If it is long and heavy, the swaying motion of the cord when plucked can be followed by the eye, but as its length is diminished, or tension increased, the vibrations become so rapid that the eye can

no longer detect them. The cord then assumes the appearance of a fusiform figure in front of the black surface, and a musical note is produced.

387. Laws of Transverse Vibrations may be studied by means of the *monocord*, or *sonometer*, Fig. 159. It consists of a rectangular wooden box, about five feet in length, and five inches

FIG. 159.



The sonometer.

square on the ends. It must not have any bottom. The long sides may be half, and the end pieces at least three-quarters of an inch thick, and made of hard wood. The top should be constructed of soft pine as thin as possible, a mere veneer one-twelfth of an inch in thickness, in a continuous piece, with its grain true and running lengthways, is the best. A wire or string is attached to a peg at the end D, and passes immediately over a triangular-shaped piece of wood, B, called a bridge. At the other end of the box it passes over another bridge, A, thence over the pulley N, and terminates in a rod on which weights may be placed, M.

In this apparatus we may, 1st, vary the tension by changing the weight on the rod M; 2d, the thickness of the wire; 3d, the weight or density of the wire; 4th, its length, by means of the movable bridge C. The laws resulting from these experiments are as follows:

1st. *Other things being equal, the number of vibrations per second is inversely as the lengths of the strings.*

2d. *Other things being equal, the number of vibrations per second is inversely as the diameters of the strings.*

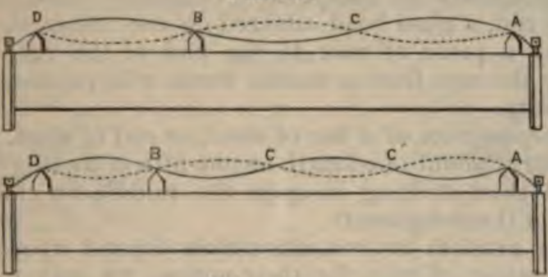
3d. *Other things being equal, the number of vibrations per second is as the square roots of the tension weights.*

4th. *Other things being equal, the number of vibrations per second is inversely as the square roots of the densities.*

These laws receive their practical applications in the construction of all kinds of stringed instruments.

388. Nodes and Loops.—Suppose the string on the monocord to be vibrating throughout its whole length, and then suddenly caught on the movable bridge B at one-third the distance from D to A. The section D B vibrates about these two new fixed points. At the same time all parts of the string tend to move

FIG. 160.



Nodes and loops.

in unison with the section D B, consequently the section B A does not vibrate as a whole, but it subdivides at C, giving two sections, B C and C A, each equal in length to D B.

Suppose the movable bridge be made to touch the cord at one-quarter its length. The results are then shown in the lower diagram, in which the remaining portion of the string from B to A vibrates in three sections, as indicated by the continuous and dotted lines. The points B C C′ A in the strings are called *nodes*. The central part of the fusiform portion of the string between these points is called a *loop*, or *ventral segment*.

The position of the nodes and loops in a vibrating cord may be made more evident by placing paper riders upon the string. Those at the nodes are quiet, while those on the loops are so violently agitated that they are thrown off.

The bridge must be made to arrest the cord at some aliquot part of its length, to form sections which bear the relation of whole numbers to each other, otherwise the nodes will not be properly formed, and the vibrations will quickly destroy each other.

389. Vibrating Rods.—All elastic rods, especially those made of steel, can be made to vibrate both transversely and longitudinally. They are excited by fixing the rod firmly at one end, and acting upon the free portion with a violin bow. To produce longitudinal vibrations, the rod is held in a narrow-jawed vice, and then rubbed in the direction of its length with a piece of cloth coated with resin.

The laws of longitudinal are similar to those of transverse vibrations. The longitudinal note given by a wire or rod is,

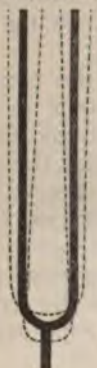
however, of much higher pitch than the transverse note of the same length of wire. This results from the fact that the elastic force longitudinally is greater than that in the transverse direction, consequently the number of vibrations is greater. A short piece of wire smartly rubbed will give a note so shrill that it is positively painful.

To demonstrate the complicated character of the motions of a vibrating rod, a glass bead silvered on the inside should be attached by a piece of wax to the end of the rod. This, by reflecting the rays from a candle flame will produce curves of great beauty.

The deepest note of a bar of steel, or rod of glass, is sounded by holding it about one-fourth or one-fifth of its length from one end, and then striking it upon the middle or end. It then vibrates in three segments.

Among musical instruments which depend upon the transverse vibration of rods for their action, we may mention the *musical snuff box* and *tuning-fork*. In the latter a rod is bent with the two nodes very near together. It vibrates as illustrated by the dotted lines, Fig. 161. The handle of the fork is not coincident with either of the nodes, but between them, so when the prongs vibrate the handle is thrown into a vigorous up and down motion, and powerful vibration may thus be imparted to any resonant surface upon which it is placed. The vibrations of the prongs may be shown by bringing one of them in the vicinity of a suspended ball of cork or pith.

FIG. 161.



Tuning-fork.

Longitudinal vibrations are employed in *Marloyl's harp*, which consists of a solid block of wood, into which some twenty thin wooden rods of different lengths are fixed. The vibrations are produced by rubbing them lengthwise by the thumb and index finger which have been dipped in resin powder; their notes resemble those of Paris pipes.

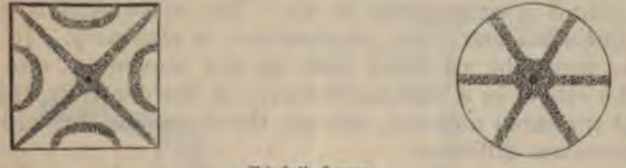
In the *triangle* while vibrations are transverse on the horizontal part, they are nearly longitudinal on the attached portions.

390. Vibrating Plates and Bells.—A vibrating plate may be either square or circular. It can be fixed either by its centre, or edge; in the first case it is thrown into vibration by drawing a bow across the edge, in the second by drawing a string covered with resin through an opening in the centre.

If a plate is fastened in the horizontal position, and fine sand dusted on its surface, on throwing it into vibration the sand

enters into rapid movement, and finally accumulates in symmetrical lines on the surface. These are called nodal lines or Chladni's figures, Fig. 162. Their position may be determined by touching the plate at the desired point. The nodal lines separate portions of the plate in which the vibration is in opposite directions. As they are determined by the parts which are touched, or fixed, they represent portions of the plate at rest.

FIG. 162.



Chladni's figures.

If lycopodium powder be mixed with the sand, the lycopodium does not move to the nodal lines, but gathers in little masses on the vibrating parts, keeping up a violent movement. After puzzling physicists for a long time, Faraday at last proved that this result was owing to inward and ascending currents of air which could act upon the light powder in the manner described. Gongs and cymbals are examples of vibrating plates, and show nodal lines.

A vibration rod when bent becomes a tuning-fork, so a bent plate forms a bell, goblet, or bowl, and is subject to the same laws of vibration as a plate. Of this we may satisfy ourselves by turning a flat bell, like those used in a clock, mouth upwards, and sprinkling sand in the interior. On sounding the bell with a violin bow, the sand shows at once the presence of nodal lines. A finger glass or tumbler in which some water has been poured, may be caused to sound by passing a wet finger along its edge. So strong are the vibrations that the water is thrown into ripples. The deepest notes are produced when the surface is divided into sections.

391. Vibrating Membranes.—Membranes can only produce sounds when stretched on a rigid framework. The smaller and the more tightly stretched, the higher the note emitted.

Membranes are also thrown into vibrations by sounds produced in their vicinity, when these are in unison with their notes. When thus vibrating, if fine sand is dusted on their surfaces, nodal lines are formed. The figures produced are not as fixed and invariable as in vibrating plates.

The sound emitted by a membrane is rather a noise than a true musical note. Their use in music is chiefly to mark the

rhythm. The sound being compound, they are, therefore, susceptible of vibration under a considerable range or variety of notes, a property of special interest in connection with the organ of hearing.

392. Vibrating Columns of Air.—Air enclosed in tubes may be thrown into vibration and originate sounds. The note depends on the length of the column of air, or of the tube. The oscillations of the air particles are similar in character to those by which sound is propagated in air. The movement is longitudinal, but *the wave is not progressive, it is stationary.* In a progressive wave the particles take up the movement one a little after the other; in a stationary wave, on the contrary, they take it up at the same moment, though the distances through which they move are different.

When a tube speaks, or emits sound, the particle at the centre does not oscillate; the rest do to a greater or less extent, those at the ends the most, and less and less towards the centre. The centre represents a node, while the end of the tube is the middle of a ventral segment. When the particles are most distant from the position of rest, the return movement begins; they overpass the position of rest, and thus a swaying motion is established.

A tube closed at one end acts like half of a tube open at both ends, the node being at the bottom, and the middle of a ventral segment at its mouth. It, therefore, gives out the same note as one of twice its length open at both ends.

Air columns may be made to vibrate in various ways. 1st. By blowing air across the mouth of the tube. In Fig. 163 the vertical cylinder represents the mouth of a tube or bottle. By means of an India-rubber tube, pinched between the fingers to form a slit, a blast of air is directed across the mouth of the cylinder, when its proper note is sounded. The flute, whistle, and certain organ pipes are examples of this method of producing vibrating columns of air.

Another method is represented in Fig. 164. In this a tuning-fork is made to vibrate over the mouth of a tall narrow jar. Water is then poured into the jar until the column of included air is of the proper length to vibrate in unison with the fork.

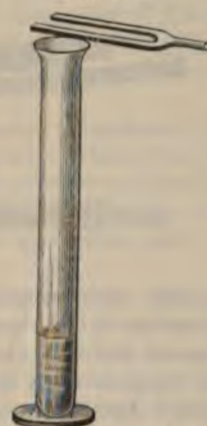
A third method is thus described by Weinhold: "If a current of air is blown between two flexible bodies which are in moderately firm contact with one another; as, for instance, between the closed lips, or between the fingers of the hand placed flat upon the mouth, or between the lips and a leaf held close before them, a sound may be produced which is caused in a similar manner to that of the siren (407). The compressed air forces its way out by slightly pushing aside the two bodies; which, in

consequence of their elasticity, instantly return to their original position, and are immediately afterwards again pushed back by the current of air; the same movement is repeated many times in rapid succession; a series of impulses is thus given to the air, and a note is produced. The pitch of this tone naturally depends, as in other tubes, upon the length of the vibrating column of air."

Fig. 163.

Sounding tube.

Fig. 164.



Vibrating column of air.

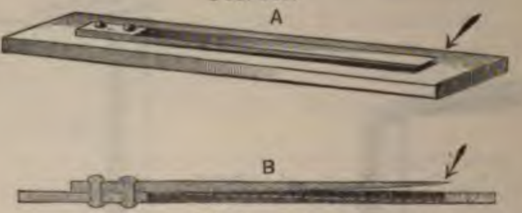
"It is thus that notes are produced in all wind instruments, except the flute. In brass instruments the lips form the soft vibrating parts; in wood instruments, for example in the clarionet, the air is forced through 'reeds,' formed of two thin elastic plates of wood or cane."

393. Reed Instruments.—The soft elastic plates of wood, cane, or reed, used in the clarionet and similar instruments, differ essentially in action from the strong springy tongues in the concertina, accordeon, harmonium, and reed pipes of the organ. In the former, the length of the column of air controls the rate of vibration of the reed; they are called mouth instruments. In the latter, the rate of vibration is independent of the column of air, it is governed, as in the tuning-fork, by the length, thickness, and shape of the tongue or reed. Therefore, they are called reed instruments.

"In reed instruments the metal tongues are thin, long, narrow rectangular plates of hardened brass or German silver, fixed by their thicker ends upon a plate of metal, usually of zinc, nearly closing a rectangular slit in the plate. In Fig. 165, A represents the exterior, B a section of such a tongue. The

plate with the tongue fixed upon it is called a 'reed;' it is fastened forming one side of a small box into which air can be forced through an opening. That side of the plate upon which the tongue is fixed is turned towards the inside of the box; as the current of air escapes from it, it presses the tongue in the direction of the small arrow into the slit of the plate, as indicated by the dotted line; the slit is for an instant more completely closed than before, and the current of air

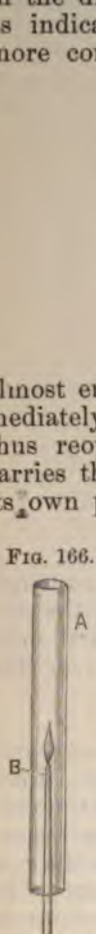
Fig. 165.



Vibrating reed.

almost entirely interrupted. The elasticity of the tongue immediately causes it to return to its first position: a passage is thus reopened for the air; the current is reëstablished and carries the tongue with it, as before, so as again to obstruct its own path; the tongue then springs back, and the action is repeated so long as air is forced into the box. If the tongue is simply bent down with the finger and released, it will vibrate to and fro, but no sound, or only a faint trace will be heard; hence, the sound is solely due to regular periodic interruption of the current of air, as in the siren."

Fig. 166.



Singing flame.

394. Singing Flames.—Musical sounds may also be produced by causing a gas flame to burn in the interior of a tube. An apparatus of this description has long been known as the *chemical harmonicon.* It consists of an arrangement for the generation of hydrogen (164), in which the escape tube B passes directly upwards from the decomposition bottle, and is drawn to a fine jet, Fig. 166. After a sufficient amount of gas has been allowed to escape, and there is no longer any danger of an explosion, the gas is lighted. Glass tubes of different length and diameters, and open at both ends, are then lowered over the flame, as at A. At certain positions in some of these tubes the flame vibrates and sounds or musical notes are emitted.

The cause of vibration under these circumstances is an irregular union of the gas with the oxygen of air. By some it is

called explosive. The manner of union of the two gases, and the rate of production of "explosions" are determined by the relations of the size of the flame to the diameter and length of the tube. Sometimes the sound is a rattling noise, at others a low, and then a high musical note.

If, while the flame is singing, we observe its reflection in a mirror rotating on a vertical axis, it is seen to be alternately increasing and diminishing. A series of images of the flame, consisting of elongated equidistant tongues with depressions between them, is thus produced, and the cause of the pulsations exposed. A coal-gas flame escaping from a circular jet, like that at B, may be used instead of the hydrogen flame.

395. Sympathetic Vibration is also called vibration by influence. It may arise in two ways: 1st. By direct contact with the vibrating object, and transmission of the sonorous undulations therefrom. 2d. By transmission of the waves through air without any direct contact of the two sounding bodies, and when they are at a distance.

Of the first form we have an example when the end of the handle of a vibrating tuning-fork is placed on a table or other resonant surface. The vibration is then communicated to an extended area, and the sound greatly increased, though it does not endure so long a time. Examples of the application of this principle are found in the sounding boards of pianos, violins, and many other musical instruments.

Instances of the second form of sympathetic vibration are offered whenever the right note is sounded in the vicinity of a sonorous body capable of emitting that note. If, for example, a given note is struck on some instrument in the proximity of a piano, tuned in harmony therewith and with the dampers raised, the proper string on the piano is instantly thrown into vibration, and it answers back the note received. If two glass cylinders of similar dimensions are adjusted by pouring water into them until they give forth the same note, and one is sounded, the other at once takes up the note, and continues to give it forth long after the first has become silent. A harp, or guitar, may often be heard taking part in the conversation in its neighborhood. The jingling sounds given forth by wine and other glasses when a piano is in action, arise in the same way. The violence of the tremor produced is frequently so great that a goblet may, by sounding a note on a violin near by, be made to fall on the floor if the table be slightly inclined and bare of covering.

396. Sensitive Flames.—Gas flames may in like manner be adjusted to be affected by certain tones, and respond to them whenever produced in their vicinity. The best way of form-

ing such a *sensitive flame* is to burn coal-gas under sufficient pressure from a conical orifice to make a tapering flame about fifteen inches in length. If the hands be clapped in the vicinity of such a flame, after it has been properly adjusted, its tall quivering form instantly drops to half its height. It may spread out laterally and assume the fish-tail shape. The moment the sound ceases it instantly reassumes its proper form.

Sensitive flames take cognizance of a great variety of sounds; a tap on a table, clinking of money, creaking of shoes, crumpling of paper, shaking a bunch of keys, all throw it into a state of excitement.

If a person whistle in the presence of a sensitive flame, when the proper note is produced it instantly shrinks and echoes back the same note. To a hiss such flames are especially responsive, they will quiver every time a word containing the letter *s* is pronounced in their vicinity, though the person speaking passes away to a considerable distance.

While affected by a great number and variety of sounds, sensitive flames do not respond to the bass notes of a piano. High notes on a violin affect them, and they will dance in perfect time to a tune played on most musical instruments.

397. Production of Abnormal Sounds in the Chest.—According as the lungs, heart, and arteries of the chest are affected by disease, certain abnormal sounds appear which are indicative of changes which have taken place therein (379).

In diseased conditions of the lungs the normal respiratory murmur produced by the transit of air along the passages becomes greatly altered. These changes are effected in various ways: 1st. The secretion of the mucous membrane may be deficient in quantity, thus a dryness is created by which the ordinary respiratory murmur becomes exaggerated by friction arising simply from the passage of air over a dry instead of a properly lubricated surface. 2d. There may be accumulation of fluid in the air cells and minute or capillary bronchi communicating therewith. The bubbling of air through this gives rise to a fine crackling or crepitant sound. 3d. Plugs of tough mucus accumulating in the medium sized and large bronchi are thrown into vibration by the passage of air. The gaseous contents of the tubes are thus caused to oscillate, and hissing, squeaking, crowing, whistling sounds arise, these are the râles and rhonchi of which physicians speak, and which may often be heard at a distance of some feet from a person suffering with bronchitis. Finally the lung structure may become consolidated and the admission of air prevented; this, of course, is attended by complete suppression in the affected part of all natural sounds produced during healthy respiration.

Passing from consideration of changes in the interior of the lung to those which take place in its covering membrane, or pleura, and the cavity in which the lung is suspended, we find: That when fibrinous matter appears on the surface of the lung, or on the inner wall of the chest, the membrane or pleura losing its smoothness becomes roughened; the two surfaces no longer glide over in a noiseless manner, but various rubbing, and other harsh sounds arise which indicate the change that has occurred.

In health the sounds of the heart are expressed by the syllables lubb-dup. Of these the second is simple, it is evidently caused by closure of the semilunar valves. The first is compound, being possibly partly muscular, but chiefly valvular, and corresponding to closure of the auriculo-ventricular openings. With diseased conditions of the valves great changes in the heart sounds are produced. If, for example, their lips are roughened by fibrinous or osseous deposits, vibrations are created which originate new or abnormal sounds that attend the sound or passage of blood through them. If they fail to close the openings properly, the blood passing backwards after imperfect closure originates new regurgitant murmurs, or other noises, which attend proper heart sounds.

In its passage along the great arteries of the chest, no sounds other than those of the heart are heard, but with changed conditions of the arteries, as in atheromatous or osseous deposits on their inner coat, or the formation of aneurismal sacs, noises produced by passage of the blood over rough surfaces or its entrance into the aneurismal cavity arise; these are known as aneurismal murmurs.

CHAPTER XIV.

SPECIAL PROPERTIES OF SOUND.

Special properties of sounds—Intensity of sounds—Diminution in intensity of sounds—Increase in intensity of sounds—Reinforcement of sounds—Resonance and percussion—Interference of sound undulations—Pitch or tone—Savart's wheel—The siren—The graphic method—Limits of perception of vibrations—The octave—The gamut and chromatic scale—Musical notation—Number of vibrations to each tone—Harmonics, overtones—Quality or timbre—Wave-lengths of sounds in air.

398. Sounds do not act alike upon our sense of hearing. The differences presented may be grouped under three divisions, viz.: 1st. Intensity or loudness. 2d. Pitch or height, by this we mean that it is high or low, acute or grave, in the musical scale. 3d. Quality, timbre, stamp, or color, by which terms we indicate that the same note varies when produced on different instruments; on the cornet and piano, for example.

399. Intensity of Sounds.—Regarding the cause of the loudness of sounds, a very simple experiment will satisfy us. Let a given low or bass string on the piano be struck softly, the string in emitting the note will be seen to vibrate with a small amount of amplitude. Then let the same note be struck with vigor, a much louder sound is produced, and the string is seen to have a far greater extent of vibration. As the note gradually dies away the amplitude of vibration becomes less and less until it is lost.

The intrinsic or original intensity of any sound, therefore, depends upon the amplitude of vibrations in the sonorous body, or the force with which they are executed. In comparison with waves on water it would be represented by the height of the wave (131). Doubling or tripling the extent of vibration, increases intensity four and nine times.

Lord Rayleigh determined the amplitude of oscillation in the case of waves produced by a pipe which sounded the note f^{iv}, that could be heard at a distance of 820 metres, and found it was less than one ten-millionth of a millimetre.

400. Diminution in Intensity of Sounds.—In this, as in the discussion of many other matters in connection with sound, the subject may be viewed in two ways: 1st, as regards vibrations

in the body wherein it originates; and, 2d, the waves by which it reaches the ear through the air or other conducting elastic medium.

In the present case, diminution in intensity may arise from the fact that the original vibrations in the sonorous body are small in their amplitude. Setting this cause aside, and dealing with that of the propagation through the air or other medium to the ear, we have the following causes of diminution in intensity:

1st. The effect of distance in the open air; with this all are familiar. The law under which diminution takes place is that, *the intensity of the sound is inversely as the square of the distance of the sonorous body from the ear.*

2d. Another cause is the diminution in density, or elasticity, of the air or other medium by which sound is transmitted. Of this we have an illustration in the experiment of the bell in vacuo; as the air is exhausted loudness of the sound diminishes. In rarefied air on a mountain-top a pistol report is insignificant, and the voice becomes remarkably thin and weak. In like manner, if a bell be rung in an atmosphere of hydrogen, the intensity is less than in air.

3d. Variation in the intensity of a sound at a distance is also produced by the action of winds. During a calm, sound is propagated with great facility. While a wind is prevailing, sound is better heard at the same distance in the direction of the moving air than against it.

4th. Stratification of the air exerts a singular effect in lessening the intensity of a sound. Of this, Ganot says: "Different parts of the earth's surface are unequally heated by the sun, owing to the shadows of trees, evaporation of water, and other causes, so that in the atmosphere there are numerous ascending and descending currents of air of different density. Whenever a sonorous wave passes from a medium of one density into another it undergoes partial reflection, which, though not strong enough to form an echo, distinctly weakens the direct sound. This is doubtless the reason, as Humboldt remarks, why sound travels further at night than at daytime."

"It has generally been considered that fog in the atmosphere is a great deadener of sound; it being a mixture of air and globules of water, at each of the innumerable surfaces of contact a portion of the vibration is lost. The evidence as to the influence of this property is conflicting; recent researches of Tyndall show that a white fog, or snow, or hail, are not important obstacles to the transmission of sound, but that aqueous vapor is. Experiments made on a large scale, in order to ascertain the best form of fog signals, give some remarkable results.

"On some days which optically were quite clear, certain sounds could not be heard at a distance far inferior to (even less than

one-third) that at which they could be heard during a thick haze. Tyndall ascribes this result to the presence in the atmosphere of aqueous vapor, which forms innumerable striæ that do not interfere with its optical clearness, but render it acoustically turbid, the sound being reflected by this invisible vapor just as light is by a visible cloud.

"In 1822 experiments were made on sound by a commission near Paris. In these cannon were fired at two stations twelve miles apart. On one occasion, while all the shots fired at the first station were heard at the second, only one out of the twelve fired at the second were heard at the first. As there was no wind at the time to account for this difference, Professors Stokes and Reynolds explained it upon the theory of refraction (385). The rays of sound, they said, like those of light and heat, are subject to refraction when they pass from one medium into another of a different density. The sound under these circumstances is lifted from the ground, and may be heard at a high but not at a low level.

"These conclusions, first drawn from observations, have been verified by laboratory experiments. Tyndall has shown that a medium consisting of alternate layers of light and heavy gas deadens sound, and also that a medium consisting of alternate strata of heated and ordinary air exerts a similar influence. The same is the case with an atmosphere containing the vapors of volatile liquids. So long as the continuity of air is preserved, sound has great power of passing through the interstices of solids; thus it will pass through twelve folds of a dry silk handkerchief, but is stopped by a single layer if it is wetted."

401. Increase in Intensity of Sounds may be produced: 1st. By increase in amplitude of the vibration in the sonorous body. This we need not discuss.

2d. By increase in the density and conducting power of the medium through which the sound is passing. In operations in caissons, for example, when the foundations of the piers of bridges are to be laid in deep water, the compression of air may be carried to a number of atmospheres. Under these circumstances its conducting power is greatly increased and sounds become intolerably intense. The substitution of a medium of higher density and conducting power, as of carbonic acid gas for ordinary air, also increases the intensity of transmitted sound.

3d. By reinforcement.

402. Reinforcement of Sounds may be accomplished in three ways: 1st. By resonance or synchronous vibrations in other bodies; 2d. By reflection; 3d. By refraction.

Resonance may be defined as a sympathetic vibration (395), resulting from the accumulation of small periodic impulses imparted by one sonorous body to another whose period or time of vibration is synchronous with it. Thus increased amplitude of movement is produced, just as when one person in swinging another gives a great extent of oscillation by repeated pushes of moderate force.

The apparatus represented, Fig. 167, was contrived by Savart to illustrate this method. It consists of a brass bowl A, which

FIG. 167.

Reinforcement of sound.

is made to vibrate by means of a violin bow. On bringing into its vicinity a hollow cylinder of card-board B, closed below and open above, the intensity of sound is greatly increased, the air in the card-board box being thrown into vibrations which are synchronous with those of the brass vessel. By moving the bottom of the card-board cylinder higher up or lower down, and varying its capacity, its point of maximum action is easily found.

The sounding-boards or boxes of stringed instruments act in a similar manner, their vibrations and that of the included air resulting partly by transmission through the bridge, and partly by sympathetic vibration through the air. The smooth curved spiral surfaces of the interior of many shells enable them to collect and reproduce sounds which reach them. Thus arises the "curious murmuring resonance" that is heard when they are held to the ear, and which in the fancy of our forefathers was ascribed to some occult influence of their ocean home.

According to some, the sound heard in a shell is the result of the contact of its mouth with the warm skin of the face, which establishes currents of air that are reverberated in its spiral depths.

The cause of reinforcement by reflection (384) arises in the fact, that a great extent of sound undulations is brought down to the same focus. It is the reverse of what happens in the dissipation of sound (377). If under these conditions of reflection,

the undulations are of considerable wave-length, they will agree so nearly in phase that there will be but little interference, and the increase in intensity will follow very closely upon increase in the condensing surface.

Reinforcement by refraction (385) is somewhat more complex in character than reinforcement by reflection. It requires the use in the convex membranous chamber of a gas denser than air, carbon dioxide, for example. The general principles are the same as for light (490).

403. Resonance and Percussion.—As we have stated in the preceding article, the accumulation of sonorous impulses by an enclosed mass of air produces resonance, or an increase in the intensity of a sound. This property of resonance has valuable applications in the art of diagnosis, as it enables physicians to determine whether a given space or cavity contains air, or not.

The simplest illustration of the resonant property of enclosed air may be obtained by tapping on the outside of a closed keg partly filled with water. While the blows are delivered on the portion occupied by water, only a dull or flat sound can be elicited; but the moment they are transferred to the portion occupied by air, a loud resonant note is produced.

In like manner, if we place the index finger of the left hand on the chest wall, and with the index and middle finger of the right hand strike quick sharp blows upon the index of the left, the chest emits a resonant sound as it is filled with air contained in the expanded lung. To this manipulation the name of *percussion* is given.

If percussion is applied in the same way to the chest of a person in whom the lung is consolidated by pneumonic or tuberculous deposits, or whose pleural cavity is filled with fluid or other exudation, only a dull flat sound can be evoked; the resonance previously obtained is entirely lost, and the result may be compared to that produced by applying percussion to the muscles of the thigh.

Any cause which increases the amount of air in the lung will add to its resonant property. Therefore, in emphysema or enlargement of the air-cells; in the formation of cavities which follows tubercle and gangrene; in perforation of the lung and escape of air into the pleural cavity, a notable increase in this respect is found on examination by percussion.

Any change in the normal area occupied by the heart is also at once detected by an increase of the area of dulness it affords on application of percussion to the chest. Tumors of all kinds, especially those which are aneurismal, indicate their presence in the chest by creating abnormal regions of dulness.

Percussion is also, at times, a valuable aid in determining the

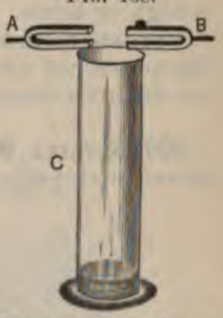
condition of the abdominal viscera. Tympanites or increase of air in the intestines, or its appearance in the abdominal cavity, is at once detected by increased resonance. Enlargement of organs, as the uterus in pregnancy, the ovaries in the growths which affect them, and the liver in certain diseases, is at once demonstrated by increase or change in the areas of dulness which they give in the normal state.

404. Interference of Sound Undulations.—In (371) it was stated that two systems of waves on water may interfere in such a manner as either to reinforce, or neutralize one another. The same phenomena arise in the case of sonorous waves.

If two systems of sound undulations pass along the same medium, the motion of any particle of the medium is determined by the motions of the two systems. If both the systems are in the same phase, the resultant is their sum. If in opposite phases it is their difference, since they partially neutralize each other; if the waves are equal as well as opposite, it is zero, and silence is produced.

For the complete extinction of two sets of sound waves the rarefied parts of one system must be the exact equivalent of the condensed portions of the other. This is not easy of attainment in actual practice. An approximate, may, however, be reached by the experiment illustrated in Fig. 168. In this A and B represent two tuning-forks of the same note, and C a glass jar into which water has been poured to bring it in resonant relation with the forks. The fork B is then armed on one of its prongs with a small pellet of wax. If either of the forks is sounded over the jar, it gives forth a clear continuous sound. But, if both are sounded at the same time, the slight difference in the rate of vibration of B produced by the pellet of wax causes the two systems of modulations to interfere, and the sound varies from moment to moment, being louder than either fork can produce alone at one moment, and fading away to silence in the next. Thus a series of beats or pulsations is produced, the sound being louder when the undulations agree in phase, and silence resulting when they are in opposite phases.

FIG. 168.



Interference of sound waves.

So long as the two notes are nearly alike, the beats are few, say from four to six in a second. When they are very different the beats become partly fused on account of their greater frequency and a harsh grating sound is produced; with a still greater difference a cutting character is assumed. This is called

dissonance, and Helmholtz states that when the beats reach 33 per second the dissonance is intolerable; beyond this the roughness lessens and when the beats reach 132 per second it disappears.

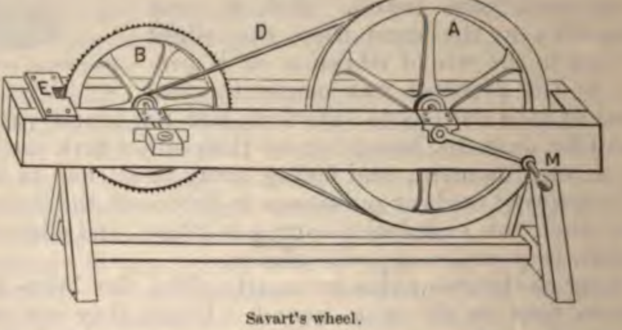
In the " Am. Journal of Sciences and Arts," vol. xii. page 329, Professor A. M. Mayer gives a very interesting account of the physiological effects of the interference of different sounds. The paper deals with the following subjects. 1st. The obliteration of the sensation of one sound by the simultaneous action on the ear of another more intense and lower sound. 2d. A sound even when intense cannot obliterate the sensation of another sound lower in pitch. 3d. Proposed change in management of orchestras in connection with these facts.

405. Pitch or Tone.—The position of a *tone* in the musical scale, or its pitch, is determined by the number of vibrations in a second. If in this time 500 oscillations are made, then 500 is called the number of vibrations, and $\frac{1}{500}$th of a second the time of vibration or period. The greater the number of pulsations the higher the pitch. This may be roughly shown by drawing the finger-nail across the teeth of a comb. If the movement is slow, and the number of strokes small, the sound is low or grave; if quick, and the number of strokes great, it is high or acute.

Various methods have been devised for the determination of the number of vibrations required to produce a given tone. They are Savart's wheel, the siren, and Duhamel's graphic method.

406. Savart's Wheel consists of a wheel, B, its circumference armed with projections or teeth like those on a cog-wheel. Its

FIG. 169.



Savart's wheel.

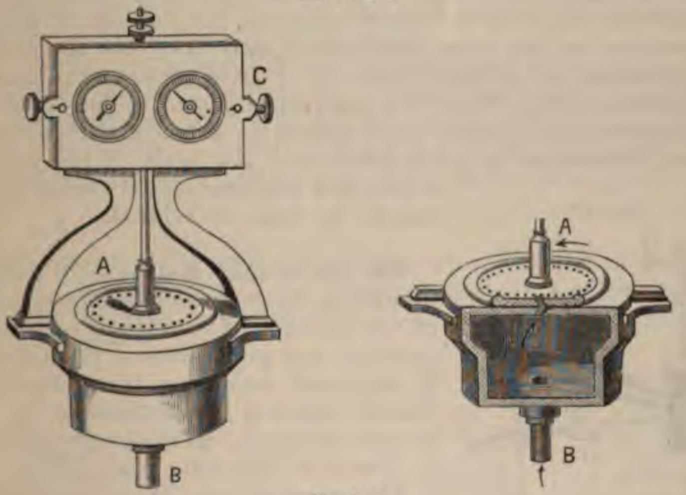
axis carries a small pulley around which a band or cord, D, passes, which receives motion from a large wheel A, driven by the winch-handle M. At E a piece of card-board is brought

in contact with the teeth of B while in rapid revolution. The striking of the teeth on the card as they pass by its edge throws it into vigorous oscillation. According as the movement is increased in rate the vibration of the card is intensified, and a higher or more acute sound is produced.

Counting the number of teeth in the wheel B, and the number of revolutions produced by each turn of the winch M, and multiplying them together, we have the total vibrations produced in the card E for each turn of the winch-handle. It only remains to determine the rate of revolution of the winch-handle to find the number of vibrations of the card per second that yields any given tone.

407. The Siren was so called by its inventor because it will give forth sound under water. In it, various tones are emitted, not by setting a solid body to vibrate, but by producing a series of puffs of air in rapid regular succession. It consists essentially of a circular series of holes in a disk of cardboard or metal, A, mounted on an axis of revolution. A tube, B, delivers a stream

FIG. 170.



The siren.

of air against one side of the disk. When the opening of the air tube is opposite one of the holes a puff of air passes through, when opposite an interval the passage of air is obstructed. By means of suitable machinery rapid revolution is given to the disk, the number of puffs of air in a given time is thus increased at the will of the operator, and any desired tone produced. The number of puffs passing through the disk is registered by

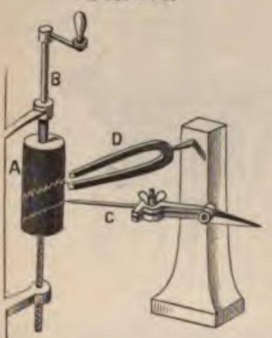
the instrument itself C, and the number of vibrations required for the sounding of any tone, is determined by merely reading the indications of the index.

Comparing the tone obtained by a given number of vibrations as recorded by the siren, with that produced by the same number by Savart's wheel, we find that their pitch is the same. In music such tones are, therefore, said to be "in unison," regardless of the instruments by which they may be formed.

In the perfect kinds of siren the rate of revolution of the disk or lid is determined by the pressure of the air employed in working the apparatus. The wind or air enters by the pipe B, from a bellows or other source, into the close box, in the lid of which is a series of holes corresponding with those in the rotating disk. The holes are not bored directly through, but obliquely, slanting in one direction through the lid of the box, and in the opposite direction through the disk A.

The disk is impelled round its axis by the wind as it issues through the lower set of holes into the upper. To apply it to the determination of the number of vibrations producing any given tone, the pressure in the siren is increased until it gives a tone in unison with that to be measured. The siren is then sounded for a given number of seconds, the number of puffs or pulsations for that time determined, and from this the number of vibrations per second obtained, by dividing it by the number of seconds during which the observation lasted. The siren thus demonstrates the cause of, and defines the exact relation between, those differences of pitch which are the basis of the musical sense, and discernible, with more or less nicety, by most individuals.

Fig. 171.



Graphic method.

408. The Graphic Method.—In both the preceding methods for the determination of the number of vibrations required to produce any given tone, a practised ear is required, and even then there is a certain amount of difference in the results obtained. In the graphic method of Duhamel this error is avoided.

The arrangement is represented in Fig. 171. A is a cylinder rotating about a vertical axis B. This is covered with a sheet of paper, on which a film of lampblack has been deposited, *by holding it in the smoke from burning camphor*. This serves as the means of registration, as follows:

Suppose the vibrations to be examined are produced by a steel rod. The rod is fixed in a vice C; to its extremity a fine wire

is attached which may be made to touch the surface of the cylinder. This being caused to rotate, and the point attached to the steel rod made to touch it, a straight line is formed by the removal of the lampblack. The rod is then struck, when at once the line produced is wave-like in character, corresponding to the oscillations of the rod.

For the determination of the number of vibrations, a tuning-fork, which emits a tone of about the same pitch as the sounding rod, and the rate of vibration of which is known, is mounted in a block D. One arm of this also bears a pointer which may be made to touch the blackened paper. The fork and the rod are sounded at the same time, and their pointers brought in contact with the revolving paper. Two systems of wave-like registrations are thus produced one above the other. The number of waves in a given extent of each system is counted, when a simple calculation gives the rate of vibration of the rod.

Suppose, for example, the rate for the fork is 500 per second, and that while the tuning-fork made 150 the rod made 165. Then, as the vibrations of the fork are to those of the rod, so is the number per second of the fork to x, the number per second of the rod; or as $150 : 165 :: 500 : x = 550$, the number of oscillations per second of the rod.

If the lower part of the axis of the revolving cylinder is a screw traversing in a nut, as the cylinder turns it will be either lowered or raised, according to the direction in which it rotates. By this device the pointers make a spiral, instead of a horizontal tracing, and records covering a number of revolutions may be obtained.

409. Limits of Perception of Vibrations.—This varies with the auditory peculiarities of the observer, and to a certain extent with the method of experimentation. The different estimates are as follows:

	Number of vibrations per second.	
	Lowest or grave tone.	Highest or acute tone.
Before Savart's time	16	9,000
Savart's experiments	7 to 8	24,000
Despretz	16	24,000
Helmholtz	30 to 40	38,000
Preyer	16 to 24	41,000

Many persons were, however, found who could not appreciate notes of 16,000 and even less than 12,000 vibrations per second.

Great variations in the pitch of notes have arisen in the progress of time. In an article by Mr. Ellis, in "Nature," vol. xxi. page 550, it is shown that for A the variations have extended from 370 to 567 vibrations per second, the present standard being 435.4, that of the "Diapason Normal," at the Conservatoire at Paris.

410. The Octave.—Two tones sounded separately may be musical, but it by no means follows that when they are sounded together they will produce a pleasing effect upon the ear. If they are not *concordant* the effect is harsh and grating. Inquiring into the numerical relation which two tones must possess to approach the nearest in their characters, we find that this is attained with the proportion of vibrations represented by $2 = 1$, $4 = 1$, etc.

So closely do two tones having the ratio of 2 to 1 in their number of oscillations approach each other, that in music they receive the same name. If, for example, the first receives the designation C, the other is called *c*, and the interval between them is termed an *octave.*

Not only does the octave, or eighth note to the first, present this peculiarity, but as we pass to the octave of this second note, and then to the octave of this, the whole series of octaves or eighth notes blend together to produce an agreeable effect. In music, therefore, the complete series of notes employed is divided into groups of octaves.

411. The Gamut and Chromatic Scale.—The series of tones into which the interval between C and its octave *c* is divided, is called the *gamut* or *diatonic scale.* It embraces seven tones, which are designated by the letters C D E F G A B.

The tones of the gamut are also known by names, *do* or *ut* standing for C, and followed by *re*, *mi*, *fa*, *sol*, *la*, *si*, in order.

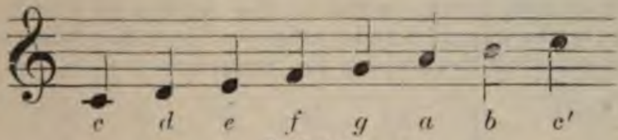
The octave is subdivisible into a much greater number of recognizable intervals than the gamut. In the musical system generally adopted five notes are added to the gamut. These are represented on the piano by short raised black keys, each of which is called the flat of the white note above, or the sharp of the white note below. To the complete series of twelve thus produced the name of *chromatic scale* is given.

412. Musical Notation.—To designate any given tone in the ordinary range of music, the following system or notation has been recommended. The octave of which the c is produced by an eight foot organ pipe, receives the capitals C, D, E, F, G, A, B. The next octave above, the letters *c*, *d*, *e*, etc.; the next c', d', e', etc. The octaves below C are designated by the capitals with the subsign, *e. g.*, $C_{\backslash}$, $D_{\backslash}$, etc. We thus obtain the series of octaves, viz.:

$$C_{\backslash\backslash}\ C_{\backslash}\ C\ c\ c'\ c''\ c'''.$$

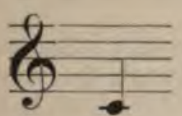
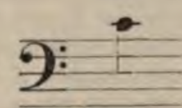
In written music, notes are indicated by signs placed upon a series of five lines, called a *stave.* According to this method, the

octave of the treble cleft, of which the top note is the standard c', and the bottom the middle c, is written as follows:



Treble stave.

When the notes pass beyond the five lines, they are written on additional short lines, called *ledger* lines, as is the case with c. For the lower notes a base cleft is employed. The base and treble may be said to meet in the middle c, written in the treble cleft as

 in the base as 

413. Number of Vibrations to each Tone.—On a piano of seven octaves the middle note c, of which we have been speaking, is produced by the white key to the left of the two black keys nearest to the middle of the key-board. Musicians have generally assumed that this note corresponds to 256 double vibrations in a second. The number is arbitrary, and was selected partly on grounds of convenience, since it is a power of two.

The adjustment of "unison," or tuning of instruments to each other, is obtained by means of the tuning-fork, described in (389). To increase the intensity of its tone, it may be fixed in a resonance box open at one end, Fig. 172. For some time past the pitch of the standard forks in the opera houses of the great European cities has gradually increased at different rates, which caused considerable annoyance to musicians in passing from one to another. To avoid the confusion thus arising, a normal tuning-fork was adopted in France. It vibrates 437.5 times in a second, and gives the standard note a of the treble stave (412). In reference to this standard the middle c on the piano is produced by 261 vibrations in a second.

FIG. 172.

Resonance box and fork.

In addition to the standard tuning-forks referred to, the English committee appointed by the Society of Arts recommended one with 528 double vibrations per second, which represented c' in the treble stave (412), or 264 for the middle c. It

is virtually the same as the Stuttgardt tuning-fork adopted in 1834, which makes 440 vibrations per second, and corresponds to a in the same stave. According to either of these values, 256, 261, or 264, for the middle c, the number of vibrations for any note of the gamut may be estimated from the following formula, m denoting the number for the middle c.

ut or do	re	mi	fa	sol	la	si	*do*
c	d	e	f	g	a	b	c'
m	$\frac{9}{8}m$	$\frac{5}{4}m$	$\frac{4}{3}m$	$\frac{3}{2}m$	$\frac{5}{3}m$	$\frac{15}{8}m$	$2m$
264	297	330	352	396	440	495	528

With the key note making 440 vibrations per second, the lowest note of orchestral instruments is the $E_{,}$ of the double bass, produced by $41\frac{1}{7}$ per second. Organs go down to $C_{,,}$, or 32, and in grand pianos $A_{,,}$ with $27\frac{1}{2}$ per second is reached. The notes below $E_{,}$ are not perfect.

On the treble side pianos reach c^{v}, with 4224 vibrations. The piccalo flute reaches d^{v}, with 4752. Though the sounds perceptible to the ear range, as we have seen (409), from 16 to 41,000 per second, or over eleven octaves, those which are capable of exciting pleasure are confined to about seven octaves, or from near 40 to about 4000.

The question of the number of vibrations producing given tones is of especial importance, since the tuning-forks originating these are employed in the physiological measurement of brief periods of time, and of rates of vibration, as in (408).

414. Harmonics, Overtones.—The formation of nodes and loops has been described in (388). When the string of the monocord is made to vibrate throughout its whole length, the sound produced is called the fundamental tone. Touching the string at the centre with the soft point of the finger, and plucking it near one end, the string will vibrate in two sections, a node being formed at the point touched. The rate of oscillation of the two ventral segments will be double that made by the whole length of the string, and the tone emitted will be an octave higher than the fundamental tone.

Touching the string again at $\frac{1}{3}$ its length from either end, it vibrates in three sections with two nodes; the number of movements is now three times that of the fundamental tone, or $\frac{3}{2}$ of the octave, which is the twelfth above the fundamental tone, and the fifth above the octave.

Again touching it at one-fourth its length from either end, and plucking it, three nodes and four ventral segments are formed, each making four times the number of vibrations of the fundamental tone, and producing the tone two octaves above the fundamental tone. This may be continued to the formation of 5, 6,

7, 8, or 12 ventral segments, each having a number of vibrations inversely as the number of segments, and producing in addition to the tones already mentioned, the third, fifth, and a tone between the sixth and seventh of the second octave, and so on.

These higher tones of a fundamental tone are called its overtones or harmonics. Whenever a string vibrates throughout its whole length, it also vibrates in halves, thirds, fourths, etc., the motion not being simple but exceedingly complex. That this is the case is proven by the fact that a trained ear can detect, in addition to the fundamental tone, its octave, twelfth, and other overtones.

If the overtones are not easily heard, they may be made evident by touching a nodal point of the string with the finger. The fundamental tone is thus stopped, while the overtones corresponding to the node touched will be heard. In this manner the presence of one overtone after another may be demonstrated.

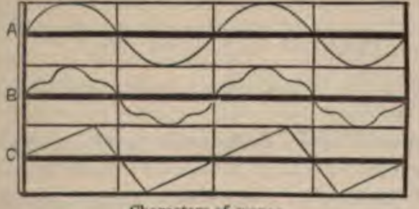
Nearly all sonorous bodies besides strings produce overtones in addition to their fundamental tone when thrown into vibration. These tones taken together constitute a *note*, as distinguished from a simple tone.

415. Quality or Timbre.—This third character of sound, by which we recognize a note of the same pitch as it is produced on different instruments, is the result of a variety of causes.

It is in part the effect of feeble sounds which attend the manner of production of the note, for example, the rushing of the air which forms the notes of a flute; the rapid or gradual decrease in intensity as in the piano, or the uniformity of intensity which attends the notes of an organ.

Another and far more potent cause of quality in a note is the nature of the overtones which accompany the fundamental

FIG. 173.



Characters of waves.

tone. These are different, not only in various sonorous bodies, but also for the same body according as the sound is produced. As these elements vary, the character of the wave produced differs, and with it the quality. The figure will enable us to perceive how this may arise.

Suppose A B C are three waves having the same amplitude and the same period. It is evident that, as shown in Fig. 173, their mode of vibration may be entirely different. It is also clear that there may be an infinite number of such variations. It is to this change in manner or form of vibration, that difference in quality is to be ascribed.

416. Wave Length of Sounds in Air.—As in the examination of the intensity of a propagated sound, the amplitude of vibration of the air-waves was compared to the height of waves on water, so in the case of pitch we may institute a like comparison, and speak of sounds as having different wave lengths. The wave length of any tone is obtained by dividing the velocity of sound (380) by the number of oscillations. From this it follows that the length of the aërial waves diminishes as the pitch of the notes rises. For shrill notes they are short and rapid, and for low notes long and slow. When the middle *c* of the piano is struck, it vibrates about 264 times in a second, and hence sets up air-pulses of 1120 feet divided by 264, or $4\frac{1}{4}$ feet in length. The first A of the bass (in a seven-octavo piano) produces air-waves about 41 feet in length, while the last *a* of the treble sends on pulses not quite 4 inches long. The latter are 128 times more rapid than the former, which are correspondingly longer. If the sensibility of the ear nerves is to be judged by the range of audibility of musical tones, it far surpasses that of the optic nerves. The former ranges over *eleven octaves*, while the latter barely exceeds a *single octave.*

CHAPTER XV.

ANALYSIS AND SYNTHESIS OF SOUNDS.

Helmholtz's resonators—König's manometric flames—König's sound analyzer—Synthesis of sounds—Results of Helmholtz's researches—Lissajou's method—Illustration of Lissajou's curves—Léon Scott's phonautograph—Edison's phonograph—Acoustic attraction and repulsion.

417. Helmholtz's Resonators.—The properties of sympathetic vibration, and resonance possessed by enclosed masses of air have been discussed in (395) and (402). In accordance therewith Helmholtz devised the apparatus called the resonator.

In its earlier form this instrument was a spherical copper or

brass vessel. On one portion of the surface there was an opening which received the sound; opposite to this a smaller opening or tubulure conveyed it to the auditory canal.

With variation in the capacity of resonators, so do they respond to different tones; it is, therefore, only necessary to be supplied with a battery of these instruments of different sizes, corresponding to the tones to be detected, and we have the means of analyzing any sound or note.

König has introduced an important modification of the original resonator; in this the body of the instrument is composed of two hollow cylinders one of which slides telescopically into the other, as shown in Fig. 174. Thus the volume of the interior can be increased or diminished, and is easily tuned or adjusted to a number of different tones. To the tubulure a rubber tube is fitted by which vibrations are conducted to any desired point.

FIG. 174.

König's resonator.

When the resonator is used one ear is carefully closed, and the rubber tube attached to the tubulure introduced into the auditory canal of the other. All sounds then appear to be stifled, and are heard as though at a distance, except when the proper tone of the resonator is produced, this at once sounds with extreme intensity, booming out clear and defined from amongst the confused hum of the others.

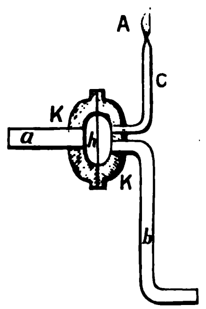
In reality the resonator not only reinforces its own proper tone, but also the harmonics of that tone; but in this case the intensity is so much less than that of the true tone of the instrument, that there is no difficulty in forming a correct opinion.

Applying one resonator after another to the ear, the presence or absence of the tones they represent in any given sound may be determined, and thus an exact analysis of the sound accomplished. By this method Helmholtz demonstrated that the quality of any note depends upon the number, pitch, and loudness of the harmonics or overtones it possesses.

418. König's Manometric Flames.—The method of analysis by resonators applied to the ear, can only be used by one person at a time. To meet this objection König has devised an ingenious apparatus, whereby a number of persons may at the same time witness the results of experiments for the detection and analysis of sounds or notes. The principle upon which this is accomplished is as follows.

In (391) we have seen that tense membranes undergo vibration when sounds are produced in their vicinity. Acting upon this fact, König received sonorous undulations upon one side of a membrane, the other being part of the wall of a small cavity or box through which gas passed on its way to a burner. When ignited at the burner, the flame by its movements at once indicated any changes in the pressure on the gas resulting from the oscillation of the membrane. In Fig. 175, the essential parts of this arrangement are represented. K K, is the box or cavity, divided into two portions by a thin membrane, *h*. The tube *a* communicates with a trumpet-like mouth-piece, along which vibrations are imparted to the diaphragm *h*. By the tube *b* illuminating gas is delivered to the portion of the cavity on the opposite side of the septum, thence it passes by the tube C to the jet A, where it is ignited.

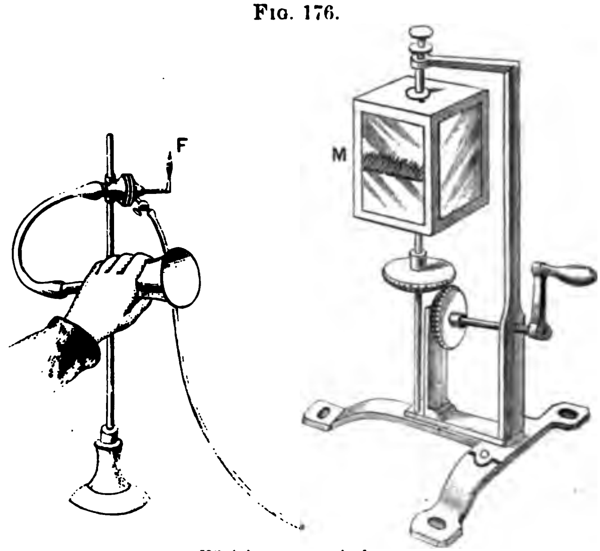
Fig. 175.



Gas-flame manometer.

So long as there is no sound in the vicinity of the mouth-piece, the gas burns in a tranquil manner, and the flame is quiet; but the instant sound is received by the mouth-piece, it is thrown

Fig. 176.



König's manometric flames.

into violent agitation, as in the singing flame of the chemical harmonicon. So closely do the movements follow each other that it is impossible for the unaided eye to determine their char-

acter; to overcome this difficulty they are viewed by means of the analyzing mirror.

This consists of a cubical box, the vertical sides formed of mirrors, M. By a vertical axis and cog-wheels, Fig. 176, it is rotated, when the reflected image of the flame F is viewed therein. When the flame burns steadily, and is not affected by sound, the image in the revolving mirrors is a simple band of light. But the moment the flame is thrown into oscillation by the action of the sound vibrations upon the membrane *h*, Fig. 175, the band-like appearance is lost, and a series of tongue-like figures appears.

Providing the note entering the mouth-piece of the apparatus is a simple or fundamental tone, the appearance produced is that in Fig. 177.

FIG. 177.

Fundamental note.

With the same rate of rotation of the mirror, if the octave of the preceding note is sounded, the result is seen in Fig. 178.

FIG. 178.

Octave of preceding.

Adapting a T-shaped tube to *a* (Fig. 175), in order that the sound of the fundamental tone and its octave may be conveyed to the flame at the same time, the effect in Fig. 179 is obtained.

FIG 179.

Fundamental note and octave.

If the fundamental note and its third be sounded, a different appearance is produced.

If the vowel o be sung on the notes *c* and *c'* it gives the result in Fig. 180.

Fig. 180.

Vowel O on c and c'.

419. König's Sound Analyzer is represented in Fig. 181. It consists of a battery of Helmholtz's resonators, to each of which a manometric flame, with capsule and vibrating membrane, is attached. The images of the flames are then viewed in the analyzing mirror.

Fig. 181.

Analysis of sound.

For analysis of any given note the resonators are arranged to correspond to it and its harmonics.

Applying this apparatus to the analysis of the same note as given forth by different instruments, it is found that the sound of a *diapason*, or tuning-fork, is almost absolutely simple; the same is the case with the flute. In the piano, on the contrary, the fundamental tone is accompanied by six harmonics; the violin shows a greater number. The clarionet gives uneven harmonics, and in brass wind instruments, like the trumpet, the higher harmonics are very intense or loud.

A crude analysis of complex sounds may be made by producing them in the vicinity of a piano, with dampers raised. The strings of the piano corresponding to the note will vibrate, and indicate the tones entering into the formation of the complex sound.

420. Synthesis of Sounds.—Not content with the decomposition or analysis of sounds into their constituents, Helmholtz has demonstrated his theory of the quality of sounds beyond cavil, by synthesis, or the putting together of their constituents.

In the apparatus by which this is accomplished the source of each sound is a diapason or tuning-fork, to which the proper resonator is attached, its mouth partly or entirely closed, and the sound intensity varied. The vibration of the fork is maintained by means of an electro-magnet. A series of such arrangements, representing a fundamental tone and its harmonics, is

provided. The fundamental tone with its harmonics in greater or less number and intensity, may in this way be sounded, and the results obtained by analysis proved.

421. Results of Helmholtz's Researches.—These are summed up as follows by Ganot:

1. Simple tones, as those produced by a tuning-fork with a resonance-box, and by wide covered pipes, are soft and agreeable without any roughness, but weak, and in the deeper notes dull.

2. Musical sounds accompanied by a series of harmonics, say up to the sixth, in moderate strength, are full and musical. In comparison with simple tones they are grander, richer, and more sonorous. Such are the sounds of open organ-pipes, of a piano-forte, etc.

3. If only the uneven harmonics are present, as in the case of narrow covered pipes, of piano-forte strings struck in the middle, clarionets, etc., the sound becomes indistinct; and when a greater number of harmonics are audible, the sound acquires a nasal character.

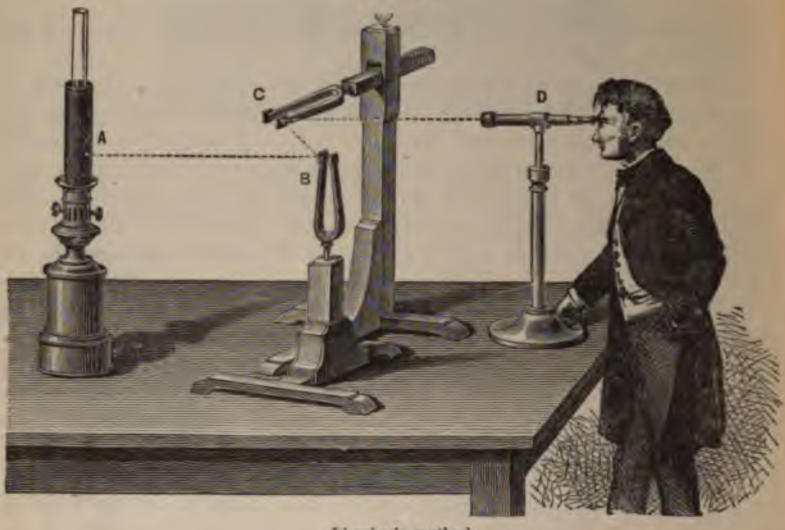
4. If the harmonics beyond the sixth and seventh are very distinct, the sound becomes sharp and rough. If less strong, the harmonics are not prejudicial to the musical usefulness of the notes. On the contrary, they are useful as imparting character and expression to the music. Of this kind are most stringed instruments, and most pipes furnished with tongues. Sounds in which harmonics are particularly strong acquire thereby a peculiarly penetrating character; such are those yielded by brass instruments.

5. To form a given vowel sound one or more characteristic notes which are always the same must be added. These change with the syllable pronounced, but depend neither on the height of the note, nor on the person who emits them.

422. Lissajou's Method consists in the production of certain figures by the action of sound vibrations upon a line of light, Fig. 182. The apparatus required for the experiment is an Argand lamp, the chimney surrounded by a cylindrical metallic screen, in which a pin-hole, A, has been made. Through this rays of light pass in the direction of the dotted line. These fall upon a tuning-fork, B, placed vertically, one prong armed with a small mirror, and the other provided with a balance weight, that the vibrations may not be changed. From this mirror the rays pass along the dotted line to a second fork C, of the same tone as the first. Its vibrations are produced horizontally. One of its prongs bears a mirror, and the other a counterpoise. At a suitable distance an observing telescope, D, is placed. The forks are in unison.

Both forks being at rest, and the angles of the mirrors properly adjusted, on looking through the telescope the image of the

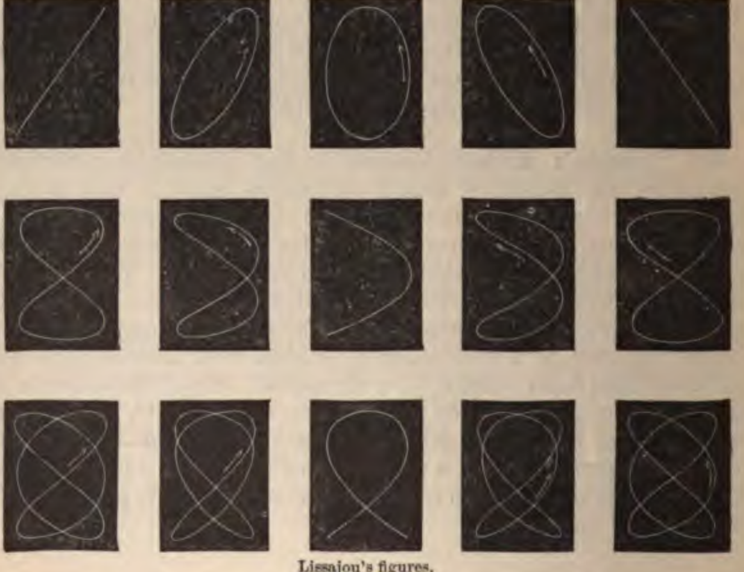
Fig. 182.



Lissajou's method.

pin-hole in the screen around the lamp chimney is seen as a minute dot of light. If one of the forks is thrown into vibra-

Fig. 183.



Lissajou's figures.

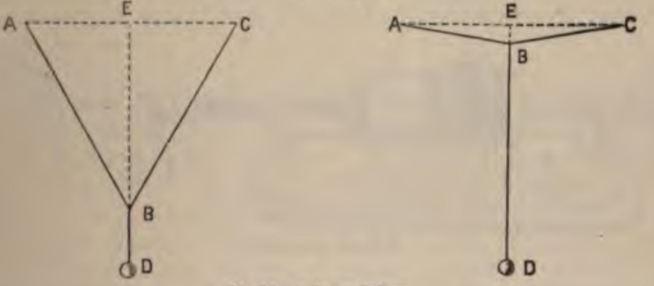
tion, the dot of light becomes a line. If the other fork alone is thrown into vibration, again the dot appears as a line, but at right angles to that previously produced. Throwing both forks into vibration at the same time, the image formed is a curve which is some form of ellipse, though oblique lines and a circle may arise as exceptional results. These are found in the upper row, Fig. 183.

If one of the forks differs from the other by an octave, the series of figures in the second row appears; if by a fifth, the curves in the lower row are obtained.

By using an electric or oxycalcium light as the source of illumination, and passing the beam therefrom through a convex lens before it falls on the first mirror, a dot-like image of the pin-hole may be projected on a screen placed in the position of the telescope. On throwing the mirrors into vibration Lissajou's images appear in perfection.

423. Illustrations of Lissajou's Curves.—By means of Blackburne's pendulum, Lissajou's curves are reproduced by a slow motion. It consists of a cord, A B C, attached at two fixed points A and C, in a horizontal line and with a certain amount of slack. To the centre of this another cord, B D, is fastened,

FIG. 184.



Blackburne's pendulum.

which carries a spherical metallic ball at D, a pointed wire projecting from the lower part. If the bob is set in motion in the plane A B C, it will vibrate in that plane, the point of suspension, B, not moving. If in a plane perpendicular to this, it will vibrate in that plane, the whole system moving with E as the point of suspension. In the one case B D represents the length of the pendulum, and gives a certain rate of vibration. In the other, E B, as it is longer, it gives a slower movement.

If the bob is drawn aside in any other plane than those mentioned, it no longer oscillates in a straight line, but executes movements resulting from a combination of those already given,

and produces curves exactly the counterpart of those of Lissajou. Preparing a little plateau of sand half an inch deep, and six or eight inches square on a board, and allowing the pointer of the bob to play therein, very beautiful figures are formed.

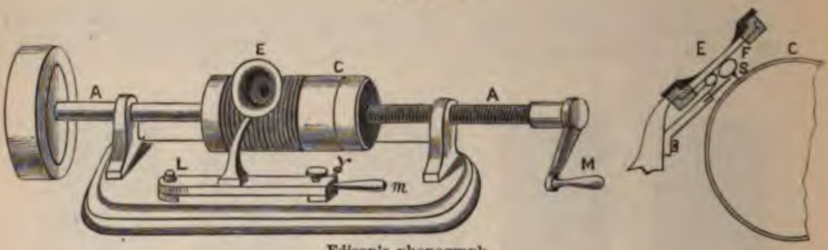
424. Léon Scott's Phonautograph is an instrument for the registration of all kinds of sounds and noises. It consists of an ellipsoidal barrel one end open, and turned in the direction of the sound. The opposite end gives passage to a narrow brass tube closed exteriorly by a delicate membrane. Near the centre of this a hog's bristle is attached, the free end touching a revolving cylinder carrying a paper covered with lampblack (408).

Setting the apparatus in movement, while sound is not received the bristle traces a straight line on the lampblack surface, but the moment sound waves enter the ellipsoid the membrane is thrown into vibration and the bristle records an undulating line corresponding thereto.

425. Edison's Phonograph is an admirable and ingenious improvement upon the preceding apparatus, as it not only records but reproduces sounds received.

Its receptive parts consist of a mouth-piece, E, into which the

FIG. 185.



Edison's phonograph.

operator speaks. The voice is directed upon a thin metallic disk, which is thrown into corresponding vibration. This metallic membrane F, carries a fine steel point S, which plays upon the cylinder C. Instead of blackened paper, the cylinder is covered with tinfoil. By means of the winch M, it is thrown into rotation, and as the axis A bears a screw cut, a movement of translation is imparted as it rotates.

The cylinder being freshly covered with foil, if the winch is rotated the steel point describes a spiral line of uniform depth thereon. Continuing the movement at a regular rate, and speaking into the mouth-piece, the unbroken spiral line disappears, and in its place a dotted line is produced, made up of depressions or perforations. These represent the record of

vibrations, similar to that in the apparatus of Léon Scott. Here, however, comparison ends, for if the cylinder of Edison's instrument is readjusted with the apex of the recording needle on the spot where the record began, by moving the winch, as the point attached to the metallic disk passes over the depressions in the foil, it throws the membrane into vibration, and causes it to give forth the sounds received from the voice.

All kinds of sounds, as singing, speaking, squeaking, hissing, may be reproduced. Even the quality of different voices is readily recognized, the only change being a slightly nasal twang or modification. Edison claims that by this machine 40,000 words can be recorded on a space of ten square inches.

Professor Blake, of Brown University, has recorded vocal sonorous vibrations by the agency of the photograph. The result was attained by attaching a steel mirror to a vibrating disk of ferrotype iron, two and three-fourths inches in diameter. A beam of sunlight was directed by a heliostat upon the mirror, and after undergoing reflection was brought to a focus by a lens upon a sensitive plate which moved at right angles to the track of the ray. So long as the ferrotype disk was at rest a linear stain was produced upon the plate, but the moment it was thrown into vibrations by the voice, a record similar in appearance to that formed by a sphygmograph was obtained. Copies of such records and a fuller description of the apparatus will be found in the "Am. Journal of Sciences and Arts," vol. xvi. page 54.

426. Acoustic Attraction and Repulsion.—A body in a state of sonorous vibration has been found to exert an influence sometimes of attraction, and again of repulsion upon other bodies freely suspended in its vicinity. Attraction is exerted when it is heavier, and repulsion when lighter. A balloon of gold-beater's skin filled with carbonic acid gas, brought near the mouth of the resonance box of a tuning-fork, is attracted. A balloon filled with hydrogen is under the same circumstances repelled, though loaded with wax.

In like manner, a tuning-fork in vibration will attract a piece of card-board suspended by a string. If, on the contrary, the vibrating fork is suspended, and the card-board fixed, the latter will attract the former. Two suspended tuning-forks while vibrating attract each other. A vibrating fork repels a candle flame placed near its extremity, or flattens it if held over it.

If very light resonators are brought near to the sounding box or resonator of a tuning-fork with which they are vibrating in unison, they undergo repulsion. If they are mounted at the extremities of a small four-armed wind-mill, the repulsion is sufficient to produce a continued rotation of the mill. These

phenomena are hardly explicable on an hypothesis of the action of currents in the air, neither can they be attributed to heat. They are of especial interest and worthy of careful investigation, as in all probability they hold the clew to the explanation of electric, and other attractions and repulsions.

CHAPTER XVI.

PHYSIOLOGICAL PRODUCTION AND PERCEPTION OF SOUND.

Voice in the lower creatures—The human voice—The larynx and song—The mouth and speech—Ventriloquism—Simple ear of lower creatures—The ear in man—The external ear—The middle ear—The internal ear—The audiphone—The photophone.

427. Voice in the Lower Creatures.—Many forms of sound-producing apparatus are found in the lower or invertebrate creatures. Sometimes, as in certain insects, it is a mere vibratory action of the wings upon the air. Again, special resonance cavities are provided, which are sounded by the friction of rough horny surfaces on each other. It is also the result of a sudden spasmodic movement of portions of the body or extremities. Even mollusks are not entirely voiceless, for certain kinds give forth booming or bell-like sounds.

428. The Human Voice.—In common with all air-breathing vertebrates, man employs air expired from the lungs for the production of voice, and establishing communication with his fellow-creatures.

For practical purposes we may consider the vocal apparatus under three divisions: 1st. The respiratory portion, consisting of the lungs, bronchi, and trachea, wherein air is compressed by the action of the diaphragm and expiratory muscles of the chest; 2d. The larynx, in which tones or notes are produced, as in simple song, by vibrations imparted to the outgoing air; and, 3d. The mouth and parts above the trachea, where sounds produced in the larynx undergo modification to form articulate speech.

429. The Larynx and Song.—The larynx may be briefly described as a box formed of articulated plates of cartilage moved

by means of muscles. It is placed at the summit of the trachea or wind-pipe, and through it outgoing air passes.

The cavity of the larynx is not entirely free, but bears upon its walls certain membranous structures, called the *vocal chords.* By the action of muscles the tension of these chords may be so changed that at one time the passage is almost without obstruction, as during ordinary respiration; while at another, it is reduced to a mere slit. When air is forced through this chink-like opening or glottis, the vocal chords or valves are thrown into vibration, and notes are sounded.

According as the tension on these chords or ligaments is varied, a higher or lower note is formed; a high note arising when the tension is greater. In their action the vocal chords may be likened to the vibrating tongues of reed instruments (393), the sound being caused by a series of impulses which arise in the reaction of the issuing current of air upon the elasticity of the reeds or vocal chords. There is, however, this important difference, that whereas the metal tongue of the reed can only yield a single note of a fixed pitch, the vocal chords emit many notes of different pitch, according to the wish of the singer.

The notes given forth by men are lower than those formed by women. Since the larynx is larger, and the vocal ligaments longer and thicker, they, therefore, vibrate more slowly and produce a lower tone. When the vocal chords vibrate throughout their whole length the so-called *chest notes* are formed; when confined to the free edges, *falsetto notes* arise.

The average extent of scale of the human voice is about two octaves. To this, important exceptions are occasionally seen. Catalini, for example, is said to have had a compass of three and a half octaves.

"Although a few exceptional singers can, so to speak, acrobatize in music to the wonder of the public, yet the really good and usable part of their compass for every-day work is comparatively limited, and if they are called upon frequently to sing either at their highest or lowest, the voice rapidly deteriorates, and wonder is changed to compassion. Violins cannot be 'screwed up or down' too much. It is better to alter the thickness of their strings. The thin strings are particularly objectionable in instruments only too prone to be played cuttingly. Clarionets, oboes, and trumpets, when made short and narrow for high pitch, are simply fit to be heard out of doors, as in military bands."

The wave length of the sounds of the ordinary voice in women during conversation is from two to four feet. With man's voice it is eight to twelve feet.

430. The Mouth and Speech.—To the larynx the mouth or buccal cavity acts the part of a resonator, causing the whole apparatus to bear a close resemblance to a reed-organ pipe.

While the intensity of the human voice depends upon the force with which air is driven through the glottis, and its pitch upon the tension of the vocal chords, the quality is the result of a variety of causes. Among these are the form of each larynx; length and elasticity of its vocal chords; resonance value and action of the buccal and nasal cavities, and other parts in the vicinity.

The chief point of interest in connection with the mouth is its agency in the formation of articulate speech. Words consist of vowels intermingled with consonants.

Since a note can only be said or sung on a vowel, these may be regarded as the essential elements of speech. Foster says, whenever a note is sounded by the larynx we recognize in it features by which we detect one or another of these sounds. Vowels are in reality exaggerated examples of quality in which certain overtones are intensified, as found by their analysis (419). The particular tones which are reinforced in the different vowel sounds may also be determined by holding vibrating tuning-forks of various tones, one after another in front of the mouth when it is arranged for pronunciation of different vowels, and observing those that have their note intensified.

The adjustments of the buccal and pharyngeal cavities by which this prominence of special overtones is produced, is illustrated as follows. When for example, *e e* in feet, or *a* in fat, is sounded the larynx is raised, the lips retracted, and the buccal cavity or resonator made very short. In producing *a* in father, the mouth is opened wide, the buccal cavity assuming a funnel shape with the point at the pharynx. For *o*, the same shape is again assumed, but the lips are protruded and the length of the resonator increased. The greatest elongation of the resonator tube is reached in producing *u*, with the sound oo.

By means of König's manometric flames vowels are found to have the following composition.

A, contains in addition to the fundamental tone, the 2d harmonic feeble, the 3d strong, and the 4th feeble.

E, the fundamental tone feeble, 2d harmonic strong, 3d feeble, 4th strong, 5th feeble.

I, very high harmonics, the 5th especially strong.

O, the fundamental, 2d harmonic strong, 3d and 4th feeble.

U, fundamental with 3d harmonic moderate.

In euphonious or pure speech the posterior nares are closed by the soft palate, for if a candle flame be held in front of the nostrils, it proves that air is not escaping through that channel. If the closure is imperfect, the sound at once becomes nasal in

character, and air passes from the nostrils. The nasal character is also caused when the anterior nares are closed by holding the nose between the thumb and forefinger, the nasal cavity then acting as a resonator.

Consonants arise from various interruptions and modifications of the expiratory blast of air, and are not produced by vibrations of the vocal chords. They are classified according to the manner and position of interruption, as follows:

Explosives.

Labials,	without voice	P.
"	with voice	B.
Dentals,	without voice	T.
"	with voice	D.
Gutturals,	without voice	K.
"	with voice	G (hard).

Aspirates.

Labials,	without voice	F.
"	with voice	V.
Dentals,	without voice	S, L, Sh, Th (hard).
"	with voice	Z, Zh (in azure, the French j), Th (soft).
Gutturals,	without voice	C H (as in loch).
"	with voice	G H (as in lough).

Resonants.

Labials	M.
Dentals	N.
Guttural	N G.

Vibratory.

Labial	Not known in European speech.
Dental	R (common)
Guttural	R (guttural).

A whisper is speech without sounding the vocal chords; it is produced by action of the lips and tongue upon the expired air.

431. Ventriloquism is simply an accurate imitation of sounds as they would be heard by the ear of the listener if given forth in various positions, as in a box, behind a door, or in an adjacent apartment. It implies deception both as regards distance and direction of a sound.

432. Simple Ear of Lower Creatures.—The most rudimentary form of ear consists of a sac filled with an albuminous fluid. On its walls the auditory nerve terminates in minute filaments. In the fluid there are certain hard stony particles, the presence

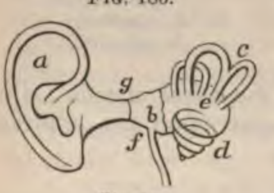
of which has caused the entire apparatus to be called an otolithic sac.

Regarding the function of the stony particles there is dispute. Some think that when sound vibrations fall on the sac, the particles are thrown into action, and produce sensation by a kind of tapping upon its sensitive wall. Others, on the contrary, imagine that their function is to act as dampers and stop vibrations as soon as they have produced their effect.

433. The Ear in Man.—In man, and in higher mammals, the auditory apparatus is very complex in its structure. We know how compound a wave of sound may be; how it involves loudness, pitch, and quality, the latter implying the superimposing of many harmonics upon the fundamental tone. It is, therefore, not at all surprising that an organ adapted to the determination of so many data, should require many parts for the accomplishment of its purpose.

For sake of convenience, the ear is studied under three divisions: 1st, external; 2d, middle; and, 3d, internal. Of these, the latter appears to be the most essential, the others occupying a subordinate position. This conclusion is based upon the fact, that in many vertebrates, and in all invertebrates, there is no true external ear. In creatures which live in water, the middle ear is also wanting, though some imagine that the swimming bladder in fishes operates in this manner, as it is connected with their auditory apparatus. Under this hypothesis it is supposed that sonorous vibrations are received from water, and passing through the body, are communicated to the air in the swimming bladder. Admitting that this is the case, the auditory apparatus in these creatures acts in the same manner as in air-breathing animals.

Fig. 186.



The ear.

In Fig. 186 the relative positions of the leading divisions of the ear are represented. The external extends to the line g; the middle from this line to the zig-zag line beyond b; the rest comprises the internal portion or division. Each of these parts consists of subdivisions, the most important of which we shall describe.

434. The External Ear.—This division consists of the pinna a, or major portion of the external organ which leads to the auditory canal or tube, by which sonorous vibrations reach the tympanic cavity or middle ear. The smooth portion of the pinna at the entrance of the tube is sometimes designated as

the concha. This term is also applied to the whole expanded part of the external ear.

In the majority of mammals the pinna or concha is very movable, and is directed to the point whence sound is proceeding. In man this is not the case, the appreciation of direction being accomplished by moving the head, though in some persons there is a slight power of movement of the ears.

It need hardly be added that, the function of the pinna is to collect sounds from a greater area, and so increase the intensity of the vibrations transmitted by the auditory canal.

In the formation of the external ear of mammals, the followers of Darwin find one of their arguments in support of the hypothesis of the origin of man from the lower orders. On the outer cartilaginous curve of the human ear, and above the opening of the auditory canal or meatus, there is a little tubercle of cartilage, which in the ears of many people is exceedingly well marked. This, philosophers tell us, is the remnant of the tip of the ear of the lower animals, and is regarded as evidence of the source from which the human organ has been developed. It is certainly very curious and interesting to note, in different individuals, that the passage of the ear through what may be called Satyr type to its perfect form may be easily traced.

435. The Middle Ear.—Entering the petrous part of the temporal bone, the auditory canal expands to form the cavity of the middle ear *b*. This is separated from the canal by a membrane which occupies the position *g*, Fig. 186. It is called the drum membrane, or membrana tympani. The drum or middle ear is filled with air, and to insure equality of pressure on each side of the membrane a tube *f*, called the Eustachian tube, communicates with the back part of the mouth. Stoppage of this tube by mucus, or otherwise, is at once attended by a muffling of the sense of hearing.

Across the drum cavity *b* a chain of three little bones is extended. They are called the *malleus*, *incus*, and *stapes*. The handle of the malleus is fixed by its top near the centre of the membrana tympani, and the stapes or stirrup to another membrane which closes an aperture leading to the internal ear, and called the *fenestra ovale*. To these little bones certain muscles are attached, which by their movements increase or diminish tension in the membrana tympani.

The function of the drum membrane is evidently to receive the vibrations which have been collected by the pinna. The peculiar facility with which such tense septa are affected by all kinds of vibrations fits it eminently for this purpose (391).

Regarding the function of the chain of bones there is dispute. Some conceive that their chief duty is to convey sonorous

vibrations to the internal ear; to this the jointed structure is an objection. Others, on the contrary, think that since they serve as attachments for delicate muscles, they merely aid the latter to determine the amplitude of vibration of the membrana tympani, by the force they exert to hold it tense, and so measure the intensity of sounds falling thereon.

436. The Internal Ear is also called the *labyrinth*. This differs essentially from the other parts in that it is filled with liquid instead of air. It consists of three portions: 1st, the vestibule or entrance, Fig. 186, *e*; 2d, the cochlea, *d*; and 3d, the semicircular canals, *c*. On, and in these, the ultimate filaments of the auditory nerve are distributed.

The *vestibule* is the entrance to the cochlea and canals; it is represented at *e*, Fig. 186. Floating in the fluid with which the cavity is filled is an ovoid membranous sac, constricted at its centre; and dumb-bell like in shape. To the two divisions the names of *saccule* and *utricle* are given. It is also filled with fluid, called the *endolymph;* that on the outside is called *perilymph.* The membranous walls of this sac receive a copious supply of nerve fibres, and in its interior minute stony particles are found; in its entirety it resembles the otolithic sac of inferior animals.

In addition to its use as the way of approach to the innermost portions of the ear, the vestibule, from its structure, evidently has some other function. What this is, it is difficult to say. Its resemblance to the otolithic sac of lower animals favors the supposition that it serves for the mere detection of noise.

The *cochlea*, represented at *d*, Fig. 186, is so-called from its resemblance to the spirally coiled shell of a snail or other gasteropod mollusk. It may be described as a conical tube, the axis very long compared with its diameter. This tube is wound spirally around a central axis. The *spiral canal* thus formed is divided throughout by a septum, called the *lamina spiralis.* This bears the so-called organ of Corti; in its structure it may be likened to a piano, which involves no less than some 3000 nerve fibres or strings.

In (419) we have learned that the resonators of Helmholtz in König's apparatus for analysis of sound, respond by their sensitive flames to the fundamental and overtones of any note in their vicinity. So the fibres of the organ of Corti, acting like resonators, determine the fundamental tone, or pitch, and the overtones, or quality, of each note that gains access to the cochlea.

We have disposed of the measurement of intensity, pitch, and the quality of sounds, yet there still remains a very important part of the labyrinth the function of which is involved in obscurity, viz., the *semicircular* canals. These are three small

tubes, represented at *c*, Fig. 186. They are each bent in the form of a semicircle and arranged to occupy three planes at right angles to each other. As they embrace the dimensions of length, breadth, and thickness, it has been supposed that they determine the direction whence sounds reach the ear. This may, however, be accomplished in other ways as, for example, by biaural audition. In connection with this question, Prof. Graham Bell has published an interesting memoir in the "American Journal of Otology." From this, the following deductions may be drawn: 1st. The perception of the direction of a source of sound is possible by a single ear. 2d. It is more perfect by biaural than by monaural observation. 3d. It is more accurate in the axial line of the ears. 4th. The error increases with the departure from this line, until at 90° from the axial line it may amount to 180°. The experiments were made in a room, and represent the results obtained under conditions influenced by reflection from the walls.

437. The Audiphone is an instrument contrived by Mr. R. G. Rhodes, of Chicago. As its name indicates, it is intended to improve the hearing in persons partially deaf. In its original form it consists of a thin sheet of ebonite fashioned into the form of a fan. One side of this is curved by strings which pass from its upper margin to the handle. When in use the convex surface is turned away from the person, and the edge pressed against the front teeth of the upper jaw.

In a modified form suggested by Colladon, a strip of elastic card-board, known as satin-board or shalloon-board, is used. The edge where pressed against the teeth is varnished.

Another modification consists in the use of birch-wood veneer; this is steamed and bent into the same shape as the instrument of Rhodes, and does not require the use of strings.

For description of the telephone, the student is referred to (897).

437 A. The Photophone.—This instrument, the discovery of Prof. Graham Bell, is thus described by S. P. Thompson in "Nature." "It bears the same relation to the telephone as the heliograph bears to the telegraph. You speak to a transmitting instrument, which flashes the vibration along a beam of light to a distant station where a receiving apparatus reconverts the light into audible speech. As in the case of that exquisite instrument, the telephone, so in that of the photophone, the means to accomplish this are of extreme simplicity."

"The transmitting device consists of a plane silvered mirror of thin glass or mica. Against the back of this flexible mirror the speaker's voice is directed; a powerful beam of light is caught

by a lens from the sun and directed upon the mirror, so as to be reflected straight to the distant station. This beam of light is thrown by the speaker's voice into corresponding vibrations."

"At the distant station the beam is received by another mirror, and concentrated upon a simple disk of hard rubber fixed as a diaphragm across the end of a hearing tube. The intermittent rays throw the disk into vibration in a way not yet explained, yet with sufficient power to produce an audible result, thus reproducing the very tones of the speaker. Other receivers may be used, in which the variation in electrical resistance of selenium under varying illumination is the essential principle. The experimental details have been worked out by Prof. Bell in conjunction with Mr. Sumner Tainter. They have discovered that other substances beside hard rubber, gold, selenium, silver, iron, paper, and notably antimony, are similarly sensitive to light."

"The singular production of mechanical vibrations by rays of light is even more mysterious than the production of vibrations in iron and steel by changes of magnetization. It was, indeed, this latter fact which led the discoverers to suspect the analogous phenomenon of photophonic sensibility in selenium and in other substances. Hitherto, in consequence of the mere optical difficulties of managing the beam of light, the distance to which sounds have been actually transmitted by the photophone is less than a quarter of a mile, but there is no reason to doubt that the method can be applied to much greater distances."

SECTION VI.

OPTICS.

CHAPTER XVII.

THEORIES AND SOURCES OF LIGHT.

Optics and light defined—Theories of light—The ether—Vibrations in the ether, their rate—Sources of light—The sun—Energy of solar action, its cause—Stars, planets, and satellites—Comets—Atmospheric sources of light—Phosphorescence—Fluorescence—Calorescence—Incandescence and oxyhydrogen lights—Electric arc and light—Motion and light—Combustion or chemical action—Illumination by gas flames—Forms of gas burners—Illumination by flames from fluids—Illumination by flames from solids—Constitution of flame—Light and life.

438. Optics and Light Defined.—The study of phenomena connected with light, and their application, is called optics. *Light is that form of energy which by its action upon the retina or nervous coat of the eye produces the sensation of vision.*

Of the five special senses with which man has been endowed, that of sight is the most perfect. Seeing is believing, is one of the most ancient of all aphorisms. The sense of touch acts by direct contact. That of taste, by touching bodies soluble in saliva. Smell, by drawing in vaporous or gaseous substances through the nostrils. The ear perceives bodies when in certain conditions of vibration, and at moderate distances. Vision, on the contrary, not only assures us of the presence of bodies when vibrating in such a manner as to emit light, but also when in the presence of others from which light is in process of emission. It is, moreover, vastly superior to hearing, as it can under proper circumstances make us acquainted with objects at almost infinite distances, and give us accurate perceptions regarding their direction.

439. Theories of Light. — There are two theories of light. First, the emission or corpuscular theory. Second, the undulatory theory.

The *emission theory* is generally accredited to Newton. It assumes that luminous bodies throw off particles or molecules with inconceivable velocity in straight lines, and that these falling upon the retina or sensitive nervous coat of the eye produce the impression of light In view of recent ideas regarding "radiant," or "ultra-gaseous matter," it has been suggested that the corpuscular theory may be true, at least for the propagation of light through space, while the undulatory theory is correct as regards the relation of this form of energy to atmospheric and other transparent terrestrial media.

The *undulatory theory* was first promulgated by Huyghens and afterwards by Euler, who were unable to overcome the support given by Newton to the emission theory. It was, however, shown by Young and Fresnel that by means of the undulatory theory many phenomena of diffraction and polarization might be explained; this led finally to its general adoption.

According to this theory, all space, both intermolecular and interstellar, is filled by an exceedingly attenuated medium, to which the name of *the luminiferous ether* is given. As sound comes to us by vibration or waves in the atmosphere, *so light results from an inconceivably rapid vibration of the molecules of the luminous body; these vibrations, moreover, are transmitted through the luminiferous ether as wave-like movements, and falling upon the retina cause the sensation of light.*

In addition to these, an electro-magnetic theory of light has been brought forward by James Clark Maxwell. The main proof of this theory lies in the fact, that the rate at which an electro-magnetic wave disturbance would travel may be calculated from electrical measurements. The rate at which light travels has been determined within very narrow limits of error. The two velocities are almost identical. Maxwell's generalizations on this subject were founded on Faraday's experiments, showing that powerful magnets could rotate a beam of polarized light.

In discussing this theory before the London Institution on December 6, 1880, Dr. Lodge says: "On the one hand, electrical energy may exist in either of two forms—the static form, when insulators are electrically strained by having had electricity driven partially through them (as in the Leyden jar), which strain is a form of energy because of the tendency to discharge and do work; and the kinetic form, where electricity is moving through conductors, or whirling round and round them, which motion of electricity is a form of energy, because the

conductors and whirls can attract or repel each other and thereby do work.

"And, on the other hand, that light is the rapid alternation of energy from one of these forms to the other—the static form where the medium is strained, to the kinetic form, where it moves; it is just conceivable then that the static form of the energy of light is *electro*-static, that is, that the medium is *electrically* strained, and that the kinetic form of the energy of light is electro-kinetic, that is, that the motion is not ordinary motion, but electrical motion—in fact, that light is an electrical vibration, not a material one."

440. The Ether.—The idea of the ether, upon the existence of which the undulatory theory is based, was first introduced by Aristotle, who taught there were four mundane elements, earth, air, fire, water, and a fifth, or extra mundane, to which he gave the name of ether, "*not because of its fire, but because of its ethereal circular movement.*" Regarding the presence of some such extremely attenuated medium in celestial space, Ganot says: "Although it presents no appreciable resistance to the motion of the denser bodies, it is possible that it hinders the motion of the smaller comets. It has been found, for example, that Encke's comet, whose period of revolution is about $3\frac{1}{3}$ years, has its period diminished by about 0.11 of a day at each successive rotation, and this diminution is ascribed by some to resistance of the ether."

Concerning the nature of the ether, and the character of luminous vibrations, Deschanel observes: "From the extreme facility with which bodies move about in it, we might be disposed to call it a subtle *fluid;* but the undulations which it serves to propagate, are not such as can be propagated by fluids. Its elastic properties are rather those of a solid, and its waves are analogous to the pulses which travel along the wires of a piano rather than to the waves of extension and compression by which sound is propagated through air. *Luminous vibrations are transverse, while those of sound are longitudinal.*"

441. Vibrations in the Ether, their Rate.—"Vibrations are capable of producing other effects than illumination. They constitute radiant heat, and create chemical effects, as in photography. Those of high frequency, or short period, are the most active chemically. Those of low frequency, or long period, have usually the most powerful heating effects; while those which affect the eye with the sense of light are intermediate."

The rate of vibration also varies with the color of the light, in the case of red light being 482,000,000,000,000 or 482 (unit) 12 per second; and for violet 707,000,000,000,000, or 707 (unit)

12. In like manner, the wave length varies, being about $\frac{1}{34000}$ inch for red, and $\frac{1}{60000}$ for violet light.

As with sound, amplitude of vibration increases intensity, so with light, brilliancy is dependent upon an augmentation of the amplitude of vibration.

An advantage arises in the study of light at this point, as the visibility of its course through smoky air enables us to illustrate many properties which it possesses in common with heat. The latter may, therefore, be better understood after the former has been examined.

442. Sources of Light.—The most convenient plan to adopt in the consideration of this subject, is to divide all sources into natural and artificial. The sun, the chief source of the energy which comes to this earth from the exterior, heads the list as being the most important. With it we may associate the stars and nebulæ, which are self-luminous. Then among celestial bodies comets would follow, shining partly by intrinsic light and partly by reflection; then the planets and their satellites, which give out only reflected light.

Following upon celestial are the atmospheric natural sources, as meteors, lightning, and auroras, which originate their own light, the first by combustion, the others by electric action; and cloudlight, twilight, and rainbows, which are modifications of sunlight, resulting from reflection and refraction. To these, certain terrestrial sources, as phosphorescent and fluorescent actions, are to be added.

Among artificial sources, the 1st, from its simplicity and universal application, is combustion, whether of gas, oil, solid fat, wax, wood, or coal. 2d, on account of its intrinsic brilliancy, the electric arc. 3d, ignition either by the electic current, or by heat from an oxyhydrogen flame, or other source. 4th, mechanical action, as the impact of a bullet, or indirectly through intervention of magnetism and electricity, as in lights developed by dynamo-electric machines.

443. The Sun.—The distance of the sun from the earth was formerly given at 95,000,000 miles, recent experiments and calculations put it about 91,500,000 miles. Its diameter is 865,000 miles. Its mean density, one-quarter that of the earth.

As regards its structure, various opinions are held. Some conceive that it consists of a dark internal core, outside of this are envelopes, the first being the photosphere, or light-emitting layer; exterior to this the chromosphere, and outside of all, the corona, extending a million miles or more.

Regarding the physical condition of the material which emits solar light, Professor Tait, after discussing the formation of

dark absorption lines in a spectrum, and the existence of these lines in the solar spectrum, says, page 219: "We arrive, therefore, at the conclusion that the sunlight must have come originally from some black body, or opaque substance, which is intensely self-luminous, and which may be either in a solid or in a liquid state—possibly even in the state of extremely compressed gas. However this may be, the source of light in the sun, whatever it is, must, in so far as we can see, give off all kinds of radiations, so it is practically a black body." Again, page 248, he adds: "The source of sunlight may not be a solid or even liquid globe—it may be merely a great thickness of very hot and highly compressed gas; in fact, it seems quite possible that no portion of the sun may be as yet even liquid."

Of the chemical nature of the materials composing the sun our knowledge is still imperfect, owing to changes in the spectra yielded by various elements under different temperatures, and other causes. For information regarding these the student is referred to the admirable paper of Lockyer, in "Nature," vols. xxii. and xxiv.; and of Prof. Young, "Am. Journal of Sciences and Arts," vol. xii. page 321. It may, however, be said that a sufficient number of coincidences between the dark lines of the solar spectrum and the lines yielded by different metals have been obtained to show that the majority of metals exist in the sun. Regarding the non-metallic elements, opinion varies. In the case of oxygen, certain well-known lines which I submitted to photographic examination, are represented by exceedingly faint dark lines in the solar spectrum. These only appear when dispersion is very great, and the slit used in forming the spectrum exceedingly narrow. See "Am. Journal of Sciences and Arts," vol. xvi. page 256, and vol. xvii. page 448.

444. Energy of Solar Action, its Cause.—Since sunlight is associated with heat, the latter affords us means of making an estimate of the energy of the actions taking place in our central luminary. The experiments and computations of Pouillet and Herschel show that the heat received by the earth from the sun is sufficient in one year to melt a layer of ice about one hundred feet in thickness, covering the surface of the earth. On this basis, since "the earth occupies only a very small extent in space as viewed from the sun; if we take into account the radiation in all directions, the whole amount of heat emitted by the sun will be found to be about 2,100,000,000,000 times that received by the earth, or sufficient to melt a thickness of two-fifths of a mile of ice per hour over the surface of the sun."

Concerning the production of this immense quantity of heat, and also of light, three hypotheses have been advanced. The first was that of chemical combination or combustion, this can

now scarcely be said to have any upholders. Regarding the others, Deschanel says, "The only causes that appear at all adequate to produce such an enormous effect, are the energy of the celestial motions, and the potential energy of solar gravitation. The motion of the earth in its orbit is at the rate of about 96,500 feet per second. The kinetic energy of a pound of matter moving with this velocity is equivalent to about 104,000 pound-degrees Centigrade, whereas a pound of carbon produces by its combustion only 8080. The inferior planets travel with greater velocity, the square of the velocity being inversely as the distance from the sun's centre, and the energy of motion is proportional to the square of velocity. It follows that a pound of matter revolving in an orbit just outside the sun would have kinetic energy about 220 times greater than if it travelled with the earth. If this motion were arrested by the body plunging into the sun, the heat generated would be about 2800 times greater than that given out by the combustion of a pound of charcoal. We know that small bodies are travelling about in the celestial spaces, for they often become visible to us as meteors, their incandescence being due to the heat generated by their friction against the earth's atmosphere, and there is reason to believe that bodies of this kind compose the immense circumsolar nebula called the zodiacal light, and also, possibly, the solar corona which becomes visible in total eclipses. It is probable that these small bodies, being retarded by the resistance of an ethereal medium, which is too rare to interfere sensibly with the motions of such large bodies as the planets, are gradually sucked into the sun, and thus furnish some contribution towards the maintenance of solar heat. But the perturbations of the inferior planets and comets furnish an approximate indication of the quantity of matter circulating within the orbit of Mercury, and this quantity is found to be such that the heat which it could produce would only be equivalent to a few centuries of solar radiation."

"Helmholtz has suggested that the smallness of the sun's density—only one-fourth of that of the earth—may be due to the expanded condition consequent on the possession of a very high temperature, and that this high temperature may be kept up by a gradual contraction. Contraction involves approach towards the sun's centre, and, therefore, the performance of work by solar gravitation. By assuming that the work thus done yields an equivalent of heat, he arrives at the conclusion that, if the sun were of uniform density throughout, the heat developed by a contraction amounting to only one ten-thousandth of the solar diameter, would be as much as is emitted by the sun in 2100 years."

445. Stars, Planets, and Satellites.—Like our sun, the stars are in themselves luminous. Our present knowledge regarding them has been obtained chiefly by the study of their spectra. See spectrum analysis (647). Professor Tait gives the following as a summary thereof.

"When we compare the spectra of different stars with that of the sun, we come to some very curious conclusions. We find four classes of spectra, as a rule, among the different fixed stars which have seemed of importance enough to be separately examined. The first class of spectra are those of white stars. You see an admirable example in Vega, and another in Sirius, or the dog-star. All these white stars have this characteristic, that they have an almost continuous spectrum with few dark lines crossing it, and these few for the most part lines of hydrogen. These stars are in all probability at a considerably higher temperature than the sun. Then you come to the class of yellow stars, of which our sun is an example. In their spectra you have many more dark lines than in those of the white stars, but you have nothing of the nature of nebulous bands crossing the spectrum such as you find in the third class; still less have you curious zones of shaded lines which you have in the fourth class of stars. This classification seems to point out the period of life, or phase of life of each particular star or sun. When it is formed by the impact of enormous quantities of matter coming together by gravitation, you have the very nearly continuous spectrum of a glowing white hot liquid or solid body (or, it may be, dense gas), the sole, or nearly sole, absorbent being gaseous hydrogen in comparatively small quantity, and the spectrum having, therefore, few absorption lines. As it gradually cools, more and more of those gases surrounding its glowing surface become absorbent, and so you have a greater number and variety of lines. Then, as it still further cools, you have those nebulous bands which seem to indicate the presence of compound substances which could not exist in the first two classes, because there the temperature is so high as to produce dissociation. Still further complexity of compounds will be found in the atmospheres of the fourth class. But sometimes, as in the case of temporary stars, a spectrum of the fourth class is suddenly crossed by the bright lines of hydrogen—showing either a last effort in the discharging of red flames, or a flicker due to some last chance impact of meteoric matter. So that we can study, as it were, not the succession of phases of life in any one particular star, but different simultaneous phases in many; we can study some stars, as it were, starting into life, others getting older, others older and older; and we occasionally find a most remarkable circumstance happening with a star that has practically died out—a star which is scarcely noticeable by the

astronomer. Such a star occasionally has an outburst rendering it for a little time—sometimes for several years—as bright as Jupiter itself. One such case very luckily occurred within the spectroscope period. It was carefully examined by Huggins, and the result of the examination was to show that it was a star which had gone on cooling, or at all events had reached the lowest of its cooling stages, but suddenly became bright because of an outburst of hydrogen. Bright lines broke out across its spectrum, showing that the incandescent gas which was in its atmosphere was at a higher temperature than the star itself."

The planets which belong to our system and their moons or satellites, all shine by reflected light, which originates in the sun. They do not, therefore, present any additional points of interest. The same may be said of other celestial sources of light, with the exception of comets.

446. Comets.—Of all celestial phenomena, that of the comet with its wonderful expanse of tail has always commanded the attention of men. In ancient days they were thought to be the evidence of the anger of an avenging deity, and men sought to avert impending doom by supplications and sacrifices. The belief is now almost universal, that by collision with one of these wanderers in space, the earth will meet its destruction. While we have neither space nor inclination to enter upon the discussion of so improbable an event, there is one point regarding the structure of comets of especial interest to physicians. It is derived from the study of their spectra. Regarding them, Professor Tait says:

"Such small comets as have been observed have given spectra which are extremely well worth noticing. These observations seem to show, first of all, that the tail of a comet gives a spectrum like that of the moon, or other body illuminated by sunlight; in other words, that the tail of the comet is not self-luminous—that it shines by scattered sunlight. But the head of the comet shows in general a spectrum which indicates the presence of glowing gas; that is to say, its spectrum is not continuous, nor is it visibly intersected by dark lines. It consists of three bright bands of light, each sharply terminated towards the red end of the spectrum, and shading away upwards to the violet end. Now Mr. Huggins, who first observed this, was struck by the resemblance of this spectrum (as he saw it in the telescope) to a terrestrial spectrum which he had noted before; and going over his note-book, he found it resembled the delineation of the spectrum of a hydrocarbon, such as olefiant gas, rendered incandescent by passing an electric discharge through it."

Setting aside the question of luminosity, that of the presence

of a hydrocarbon (which might possibly be an organic body) in the nucleus of comets, has given rise to the wildest speculations. It has been suggested, and not altogether in sport, that in some occult way a comet may first have brought the germs of life to the earth.

447. Atmospheric Sources of Light.—Among the atmospheric sources of light (442), are auroras and lightning. These possess a certain interest by virtue of their relations to the electric conditions of air, and the formation of ozone, or active oxygen; and also from their effects upon the compass, and dipping needles. Since their relation to man and his interests are rather through electric than luminous properties, we shall defer consideration of them to the domain of electricity.

448. Phosphorescence may be defined as the power which many bodies possess of emitting light under the influence of certain stimuli. This is attended by little or no heat. The conditions favorable to the development of phosphorescence are:

1st. Spontaneous phosphorescences resulting: 1st, from nervous action; 2d, slow oxidation; 3d, decay of organic substances. Examples of the first are seen in certain articulates, as the glow-worm and firefly; in numerous *acalephæ*, or jelly-fish, some of which are very large; in minute rhizopods; certain tropical animalcules emit a luminous matter so diffusive, that when placed in a tumbler of water they illuminate the entire mass of fluid.

Examples of production of light by slow oxidation are seen in the case of active phosphorus and of many of its solutions.

Organic matter, both vegetable and animal, at a particular stage of decay emits light. Certain kinds of wood, among which is the willow, possess this property in a marked degree, and it is not improbable that to this cause the *ignis fatui* may be attributed. Among animal structures many fish, as herring, mackerel, smelt, when dead, often become phosphorescent in the dark. The same phenomenon has also appeared in the dying, and recently dead, human body. It disappears the moment putrefaction has fairly set in.

2d. Mechanical action; like friction, cleavage, percussion, as when two quartz pebbles are rubbed or struck against each other, or when pieces of white sugar are rubbed together or broken in the dark.

3d. Heat. In the case of many minerals, temperatures of 300° F., or less, suffice for the development of phosphorescent light. Among such bodies are certain diamonds, and particularly *chlorophane*, a species of fluor-spar.

4th. Electricity; especially in the case of sparks from the frictional machine and induction coil. The substances which become luminous by the action of this agent are generally those which attain this property when submitted to sunlight.

5th. Insolation. Many substances exposed to sunlight become phosphorescent in the dark; diffuse daylight causes the same result in a less degree. This was first observed in the case of the sulphide of barium or Bolognese phosphorus in 1604. Since then many other substances have been added to the list, their power being in the order their names are given.

Sulphide of calcium.
Sulphide of strontium.
Yellow and other diamonds.
Fluor-spar.
Calcareous concretions.
Chalk.
Apatite.
Heavy-spar.
Nitrate of calcium, dry.
Chloride of calcium, dry.
Cyanide of calcium.
Many strontium compounds.
Many barium compounds.
Many magnesium compounds.
Paper, dry.
Silk.
Cane and milk sugar.
Amber.
Teeth, etc.

Variously colored lights act differently with substances. The tint of the light of a phosphorescent body varies with the manner of preparation. The duration is also very changeable, from a few seconds in some, to thirty hours in the cases of the sulphides of calcium and strontium.

449. Fluorescence is by many confounded with phosphorescence. The term is applied by Stokes to the fact that certain bodies possess the property of changing the refrangibility (490) of the rays falling upon them. Among such substances especial mention is made of solution of the sulphate of quinine, which renders the invisible ultra-violet rays of the spectrum visible. A similar result occurs when these rays fall upon paper impregnated with æsculine (from the horse chestnut), or with alcoholic solution of stramonium. The crystalline lens of the eye is also slightly fluorescent. Among dense solids which possess this property is canary colored uranium glass.

In the majority of instances, fluorescence arises by the action of the more refrangible or ultra-violet rays, which undergo a diminution in refrangibility, but is not confined to these. While glass absorbs the more refrangible rays, quartz allows their passage. If a prism and trough formed of quartz are used, and the spectrum received on paper imbued with solution of sulphate of quinine, two spectra are obtained, that on the quinine portion extending beyond the line H, to a distance equal to the whole visible spectrum.

Fluorescence may be shown without the use of a prism. Let light be admitted through blue glass into an otherwise dark

room, hold in the track of the blue light a test tube partly filled with solution of the sulphate of quinine, on which ethereal solution of chlorophyle has been poured. By transmitted light the quinine will appear colorless, and the chlorophyle green, while by reflected light the quinine will be blue, and the chlorophyle red.

By the electric light and quartz apparatus fluorescent spectra of great length may be obtained. Some flames of moderate illuminating power produce marked effects. Writing made with stramonium solution is invisible by daylight, but if illuminated with the flame of burning sulphur, or sulphide of carbon, it instantly appears.

450. Calorescence is a term applied by Tyndall to the fact that invisible heat rays may be transformed into bright light if received upon certain opaque surfaces. His demonstration of this fact is as follows: The light from an electric arc is passed through a rock-salt cell containing iodine dissolved in sulphide of carbon. This stops all the rays of light, but allows the heat rays to pass freely. These being received upon a concave mirror are brought to a focus which is invisible, but the moment a piece of thin platinum foil is placed therein it becomes luminous, emitting a white light which shows all colors of the spectrum when viewed through a prism. In this case light is in no way the product of chemical action, as with numerous other substances that might be used. The platinum comes out of the ordeal unchanged as far as oxidation is concerned. The light has, therefore, arisen solely from the conversion of dark radiant heat into bright rays.

451. Incandescence and Oxyhydrogen Lights.—The term incandescence is generally used to indicate the emission of light by a solid or liquid by virtue of elevated temperature, and independently of any chemical action in the luminous body. In the preceding article on calorescence, the platinum is incandescent. The same effect is produced when it is plunged in the almost invisible flame of pure hydrogen.

Among the best examples of incandescence are the lights produced when a burning oxyhydrogen jet impinges upon certain oxides, as lime, magnesia, and zirconia. These solid bodies under the intense heat become highly luminous. There is no proper chemical action, though a portion of the oxide undergoes volatilization, the zirconia less than the others.

For the purpose of class room demonstration by the projection of photographs, or microscopic objects upon a screen, these lights are well adapted. They do not possess the intrinsic brilliancy of the electric arc, but they are steady, and not so

trying to the eyes. By virtue of its low power of volatilization, the zirconia light offers the most satisfactory results. For the preparation of this oxide, and the formation of pencils or cylinders suitable for the oxyzirconia light, the student is referred to an article I published in the "American Journal of Sciences and Arts," for Sept. 1877, page 208.

Another, and very interesting example of incandescence results when an electric current is forced to pass along a narrow conductor, as, for example, a thin platinum wire, or a thin channel of charcoal enclosed in a vacuum, or an atmosphere which is a non-supporter of combustion. The recent application of this method for artificial illumination is well known.

In all the cases cited, analysis of the light by a prism shows a continuous spectrum, containing all seven colors, though there is more or less variation in intensity in different regions. A magnesium light, being very rich in the more refrangible and chemical, and the zirconian in the less refrangible and heat rays.

Incandescence in liquids does not show any great difference from that in solids. The phenomena are best seen in molten metals the volatilizing point of which is sufficiently high.

Gases and vapors may also be rendered incandescent by means of electricity; especially is this the case when the spark from an induction coil is employed, and a condenser intervened in the course of the current. The spectrum, under these circumstances, ordinarily consists of certain colored bands or lines. If, however, the gas is compressed, and the temperature sufficiently intense, there is reason to suppose that the spectrum may become continuous, as with the photosphere of the sun, which is generally thought to consist of highly condensed gaseous matter at an exceedingly high temperature.

452. Electric Arc and Light.—When the poles of an electric battery are brought together and then separated, the current of electricity flows across the break (providing it is not too great for its strength), and produces the most brilliant of all artificial lights. Any conductor will answer for the formation of the electric arc, but for its continuation for a length of time only the most infusible substances can be employed. It is, therefore, found, in the practical application of this light, that rods made of gas-carbon are to be preferred to all others, on account of the comparative incombustibility, and resistance to volatilization.

Even in the electric arc conveyance of matter from one pole to the other takes place. It is, therefore, not at all improbable that the light is that of incandescence either of a solid, liquid,

or gaseous body. This view is borne out by the fact, that the spectrum is continuous.

453. Motion and Light.—When a ball from a heavy piece of ordnance strikes an iron target, at the moment of impact a bright flash of light is seen. Herein we find the conversion of motion into light. At the same time heat is also developed, as is proven by the fact, that the temperature of minute portions of the missile, or target, are raised sufficiently high to cause their fusion.

The practical conversion of motion into light is admirably illustrated in modern dynamo-electric machines. By their agency, energy derived from combustion, gravity, or any other source, is, through the intervention of magnetism, made to produce electric currents. So great is the power of these currents, that they far surpass that of any electric battery thus far constructed. The importance of this source of light cannot yet be estimated. Obtaining motion from falling water, or from tidal action, its cost after the construction of the necessary machinery is insignificant. Experiments have thus far shown its adaptability for out-door illumination, and any day may witness the perfection of means for its utilization for household purposes.

454. Combustion or Chemical Action.—Though the burning of phosphorus and magnesium yield brilliant light, yet, from a practical point of view, only combustions in the air of bodies rich in hydrogen and carbon deserve our attention. Among these we may consider: 1st, illuminating and other kinds of gas; 2d, fluids, as different kinds of oils, alcoholic and other solutions; 3d, solids, as fats, wax, resins.

The question of artificial illumination in dwellings, is one physicians cannot afford to neglect. Especially in diseased conditions of the eye is its consideration paramount. We shall, therefore, devote sufficient space to its examination, to give a clear account of the principles involved, and the best means for their application.

455. Illumination by Gas Flames.—The simplest case of combustion is that offered by ordinary illuminating gas; for the sake of convenience, we may regard it as being practically pure, consisting of compounds of hydrogen and carbon. Such gas may be burned with three different results:

1st. If the supply of air is insufficient, an elongated smoky flame is produced, which possesses slight illuminating power. On lowering into this any cool surface, as, for example, a porce-

lain capsule, it is instantly covered with a copious deposit of lampblack, or carbon, in a state of exceedingly fine subdivision.

2d. If the gas is mingled with a sufficient proportion of air before ignition, as in the Bunsen burner, a non-luminous pale light is obtained; lowering a porcelain surface into this, it may remain therein for some time without the formation of any deposit.

3d. By arranging the form of the issuing jet of gas to give proper exposure to the air, a highly illuminating flame is produced, as with duplex burners. Lowering a porcelain surface into this, we again obtain the deposit of carbon or soot, though moderate in amount.

From the consideration of these results we arrive at an explanation of the source of light in ordinary illuminating flames, and we find that, as in many other instances, it is produced by incandescence of matter at an exceedingly high temperature.

Recalling the case of the non-luminous flame of hydrogen, and the immediate incandescence of the platinum foil when placed therein, let us apply the same experiment to the non-luminous Bunsen flame. At once the platinum glows, and light of considerable intensity is emitted. There is, therefore, in that flame sufficient heat to develop light. Wherein lies the reason of its non-appearance?

The method employed for the production of the Bunsen flame consists in mingling the combustible gas with a considerable proportion of air before ignition. By this operation both constituents of the gas are completely burned or oxidized by oxygen of the air. The hydrogen produces vapor of water, and the carbon, carbonic acid gas. At the temperatures and pressures reached in ordinary flames, neither of these bodies possesses the power of emitting light to any extent when compared with that of a solid. Therefore, since the Bunsen flame does not contain solid matter, it is non-luminous; but the moment we place a solid, as platinum, therein, light is at once produced.

When illuminating gas is burned with an insufficient supply of air, we may say that only the hydrogen has been consumed. The carbon of the gas not being oxidized, separates as smoke or soot easily collected on a cool surface on which the flame is caused to impinge. In this case, we have a certain degree of luminosity attending the presence of solid matter, but the temperature attained by the burning hydrogen is not sufficient to heat the carbon to the requisite degree for the copious production of luminous effect.

In the third case, the supply of oxygen of the air is adjusted to produce the most intense degree of heat. The whole of the hydrogen and a portion of the carbon are burned in a small compass. The unconsumed carbon is, therefore, raised to a very

high temperature, and the luminous effect proportionately increased.

In addition to facts given showing that luminosity of hydrocarbon flames is produced by the presence of particles of solid carbon therein, we quote the following summary by Prof. Barker, of Heumasen's argument on this point.

"1st. The increased luminosity which chlorine gives to weakly luminous or non-luminous flames, is due to its well-known property of separating the carbon as such. 2d. A rod held in a flame is smoked only on the lower side, the side opposed to the gas stream; were the carbon there as vapor, as Frankland assumes, it would be condensed by a cooling action and so all around the rod. 3d. A body held in the flame is smoked even when it is in a state of ignition; this, therefore, cannot be condensation of a vapor. 4th. These particles can be actually seen in the flame when it is made to strike against a second flame or an ignited surface, the particles aggregating together to form visible masses. 5th. The luminous portion of a flame is not very transparent, no more so than the layer of smoke of the same thickness which rises above a flame fed with turpentine. And, 6th, flames which unquestionably owe their luminosity to the presence of solid particles give a shadow with sunlight, precisely as do hydrocarbon flames; while luminous flames composed of ignited gases and vapors only, give no such shadow in sunlight. 'Liebig's Annalen,' clxxxiv. 206, Dec. 1876."

To this theory of the dependence of luminosity upon the presence of solid matter at a very high temperature in flames, there are certain exceptions. Among these, we may mention the flame of arseniuretted hydrogen burning in air. Here we have a highly luminous result quite independent of the presence of any solid matter. It is true, that arsenious oxide is formed, but this substance volatilizes below a red heat. All the products of combustion are, therefore, in the gaseous state, and offer evidence that in certain conditions gases or vapors may be luminous, and not under very great pressures or temperature.

456. Forms of Gas Burners. — Ordinary illuminating gas is usually burned from jets called fish-tail or fan-lights. In the former, the apertures from which it escapes are circular, with two streams impinging upon each other producing a thin sheet of gas, which on ignition gives a flame resembling the tail of a fish. Under these conditions of combustion, when the supply and force are properly regulated by a stop-cock a very high temperature, yielding a satisfactory degree of illumination, is the result.

In fan-light burners the aperture of escape is in the form of a slit, sometimes double. The manner of action is similar to

the fish-tail; the flame, however, is much broader, being in the form of a fan. In duplex burners two flames burn side by side. They may be either gas or kerosene.

In these varieties the character of the material forming the jet sooner or later has a marked influence upon the form of the flame. If the tip is of brass or other metal, it becomes corroded, the jet is changed and the gas not burned to the best advantage. It is true the openings may be cleansed, but after this has been done a few times, they become enlarged and no longer work well. To avoid this difficulty jets are made of lava, which does not undergo change, and may be freed from dust without alteration of form.

While the fish and fan tips answer perfectly well for ordinary purposes of illumination, the flickering or irregular manner in which they consume gas is a serious objection against their use by the student. To avoid this, and at the same time procure a more intense and whiter light, the Argand burner was contrived. It consists of a series of small openings arranged in the form of a ring, air having access to the interior and exterior of a hollow cylinder of flame. By means of a glass chimney the draught or supply of air is increased, and a more intense heat and greater illuminating power attained. At the same time the flame is perfectly steady, and the injurious effects of flickering avoided. When used with a porcelain or ground glass shade or globe this form gives the best light for the student and reader.

457. Illumination by Flames from Fluids is one of the earlier methods for obtaining artificial light. The most ancient form of lamp, which is still in use in the south of Europe as a night-light, consists of a button-like disk of wood through which a short piece of cloth or coarse thread is passed. This is floated upon the surface of oil placed in a cup, and answers as a wick when ignited. With the common oil lamp, all who live in rural regions are familiar. It is a mere modification of the preceding.

Before petroleum and kerosene were introduced as sources of artificial light, it had been found that the best, purest, and brightest flame was obtained by burning oil freely supplied to a hollow cylindrical wick, in the interior of a glass chimney. No light has ever surpassed that of the Carcel or mechanical lamp, the action of which was based upon this principle, the oil being pumped up to the wick by machinery driven by clock-work. Rape seed or other vegetable oils are best suited to these lamps.

In the so-called student's lamp, a similar free supply of combustible is obtained by placing the reservoir of oil in such position that the supply of fluid is assisted by gravity, Fig. 187.

The light given by the modern kerosene lamp is admirable in

its character. The method of combustion is that employed in the Carcel and student's lamps, an increased rate of burning being obtained by means of a glass chimney. The supply of air, however, requires greater care in its regulation. The best results are attained by increase or diminution in the quantity of air, by increasing or diminishing the size of the openings through which it passes. The proper adjustment of the shield through which it is thrown upon the wick, is also necessary.

Fig. 187.

Student's lamp.

The Argand, kerosene, Carcel, and student's lamp flames, should be softened by porcelain or ground-glass shades. The light should also be prevented from falling upon the eyes, by means of opaque shades of paper or other suitable material. Especial attention must be paid to this precaution when eyes are weak or sensitive.

In the combustion of oil the fluid is practically a compound of hydrogen and carbon, and is converted into a gaseous body as the action goes on. The source of the luminous effect is, therefore, virtually the same as with ordinary illuminating gas. The method to be followed is to regulate the supply of air to burn the hydrogen completely, and the carbon in part. The combustion action should be kept within the narrowest limits, in order to gain the highest temperature, and thereby force the remaining portions of carbon to emit light of the greatest intensity. In addition to natural oils and naphthas, solutions of various combustible bodies in alcohol and other fluids have been used. Among these, camphene may be mentioned. They have, however, now been generally supplanted by the different petroleum derivatives.

458. Illumination by Flame from Solids.—The first attempt of man to utilize combustion for artificial light was doubtless the torch, made either of wood naturally rich in resin and similar compounds of hydrogen and carbon, or reeds and rushes dipped in melted tallow. Even now, savage people resort to this method of obtaining artificial light.

From the rush light to the candle, the step was natural, and though there are many flames far more brilliant than that from a wax candle, no one is so well adapted to the illumination of the human countenance. Therefore, it still holds its own at entertainments in the houses of the wealthy, ladies of fashion well knowing that under its light they appear to the best advantage.

In recent times various solid fats, resulting from the distillation and refining of crude petroleum, have been substituted for tallow and wax in making candles.

The manufacture of a perfect candle requires especial attention, as regards the manner in which the wick is woven. That it may burn to the best advantage, the tip of the wick must be consumed at the proper rate, otherwise a smoky flame is produced. In the days of our forefathers, a pair of snuffers for removal of the charred tips were provided, but candles of modern times snuff themselves. This result is attained by the ingenious device of weaving the wick in such a manner that, as the candle burns, it turns to one side and the tip is consumed on the margin of the flame, where the heat is very intense and supply of air copious.

FIG. 188.

Gas from candle flame

The philosophy of combustion in a candle is the same as in a lamp. The first action of the flame is to melt a portion of the solid fat or wax. A miniature lamp is thus formed, from the small reservoir of which the wick, by its capillarity, raises the melted oil.

As in the lamp, oil is converted into gaseous matter before it is burned, so is it in the candle. Of this we may satisfy ourselves by taking a tube of moderate diameter, B, and, holding it inclined, Fig. 188, place one end in the interior of a candle flame A. If it has been previously warmed, an upward current of gaseous matter traverses the interior, which can be lighted as it escapes from the upper extremity. The cause of luminosity is the incandescence of solid carbon at an exceedingly high temperature.

459. Constitution of Flames.—If we lower a sheet of coarse copper wire gauze into the flame of an alcohol lamp, it is stopped by the gauze, and we can look vertically down into the section. Under these conditions it appears to be ring-like, the interior being dark. There are no signs whatever of burning therein. Since the same result is obtained on the examination of all ordinary flames, we conclude that they are hollow, and that combustion is confined to the exterior. In this fact we find an explanation of the greater brilliancy when flames are forced to assume the form of thin sheets as in different kind of gas-jets, and in hollow burners of Carcel and similar lamps.

Not only are flames hollow, but their interior is positively cold, compared with the temperature we should expect to find therein. For illustration of this, take a porcelain cup two or three inches in diameter, and fill with water nearly to the brim. On the surface pour a layer of ether a sixteenth of an inch thick. Setting fire to the ether a copious blaze is produced. If a piece of phosphorus is placed in a spoon and ignited, it burns fiercely in the air, but the moment it is immersed in the interior of the flame, not only does combustion cease, but the phosphorus does not volatilize with any freedom, thus verifying the statement, that a flame is hollow, and its interior cool.

An exception to this condition is found in *oxyhydrogen flames*, in which the gases are mingled before ignition, combustion taking place through and through. Such flames are, so to speak, solid, and therefore we understand why they possess such intense heat, and can produce the highly luminous effect witnessed when caused to impinge upon zirconia, and similar oxides.

In the *Bude light*, formed by saturating ordinary illuminating gas with volatile hydrocarbons, and burning the product in a state of mixture with oxygen, an exceedingly brilliant light is produced. The cause of the intensity is evidently the high temperature reached by making the flame burn through and through, and confining it to the smallest possible limits.

460. Light and Life.—In closing this Chapter on the sources of light, we direct attention to the intimate relations between light and life. It is to the sun's rays that plants are indebted for the energy by which they are enabled to decompose water and carbonic acid, and build tissues therefrom. It is true, as I stated in an article on "Evolution of Structure in Seedlings," published in the "American Journal of Science and Arts," for November, 1872, that plants can evolve all their structures in the dark. Yet in this act they depend entirely upon nutriment stored in the seed. No substantial gain in solid matter is made in any flowering plant until light falls upon its leaves and carbonic acid is decomposed. Plants being the source from which animals ultimately derive their sustenance, we may truly say that all life upon our globe results from energy given forth by the sun in the form of light and warmth.

Independently of the question of nutrition, light appears to exert a notable influence upon the life of young growing creatures, and even of adults. Evidence of this is found in the puny forms and blanched appearance of children living in dark, unwholesome places, compared with those where light has free access. This fact was taken advantage of a few years ago by a society in France, which collected miserable waifs born

of scrofulous and syphilitic parents, and feeding them upon milk, kept them in the sunshine all day at the sea-coast. Under this treatment, most of these infants developed into healthy, hardy youngsters, and the results were attributed by those in charge as much to free exposure to light as any other cause.

Reversing the relations, we discover (448) that many creatures possess the power of emitting light. *The significance of this production of light by nervous or vital action can hardly be overestimated. It proves to us how intimate the connections are between all forms of energy, not excepting life itself.* So strongly has this been impressed upon many minds, that there are those who think that life after all is only a specific form of energy, and that the "vital spark" is a literal as well as metaphoric expression of the facts of the case.

The recognition of the relation between light and life receives innumerable illustrations in the world of literature. In dealing with the question of condition and place of abode of the spirit after death, an ancient writer asks, "Whither goeth the flame when it is puffed out?"

CHAPTER XVIII.

TRANSMISSION, ABSORPTION, AND INTENSITY OF LIGHT.

Transparent and absorbent media—Propagation of light in homogeneous medium—Ray, pencil, and beam—Shadow and penumbra—Images from small openings—Velocity of light—Qualities of light—Laws of intensities of light—Photometers—The candle and other light units—Relative intensities of different sources of light.

461. Transparent and Absorbent Media.—The term *medium* is understood to include space as well as gaseous, fluid, and solid bodies. Through the most perfect vacuum that can be formed, light passes as freely as through air, or any colorless gas; the mere fact that it allows the passage of luminous vibrations causes it to be regarded as a medium.

In their relations to light, media are classified into transparent, translucent, and opaque. *Transparent* media are those which not only permit the passage of luminous rays, but also allow the outline and color of objects to be clearly seen through them. In this group, air, colorless gases, water, humors of the eye,

lass, rock-crystal, and many other bodies are included. They re sometimes called *diaphanous*. *Translucent* bodies allow the assage of light, but do not permit definition of outline when at short distance therefrom. Examples of this form are found in lass ground on both sides, porcelain, oiled paper, etc. They re called *opalescent*. *Opaque* bodies are those which cut off all assage of light, as wood and metals. By such substances it is aid to be absorbed. It does not, however, disappear, but is onverted into another form of energy, as, for example, heat.

Transparency and opacity are, at the best, relative terms. ven the purest air reduces the brilliancy of the light which raverses it. Dense metals, as gold and silver, may be obtained layers thin enough to be transparent, as in the process for the eposition of silver on glass in making silver mirrors.

Regarding the absorbent action of air on the light traversing , Bouguer gives the following results according as the angle of levation of the sun varies. 10,000 is supposed to represent the ntensity of light, if the air was absolutely transparent:

Sun's altitude.	Intensity.	Sun's altitude.	Intensity.
0°	6	20°	5474
1°	7	25°	6136
2°	192	30°	6613
3°	454	40°	7237
4°	802	50°	7624
5°	1201	70°	8016
10°	3149	90°	8123
15°	4535		

The table is of value as showing the great difference in the ght transmitted during summer and winter, according as the un varies in altitude.

462. Propagation of Light in Homogeneous Medium.—A homoeneous medium is understood to be one which has the same hemical composition, and the same density in all its parts. hrough such, if it be transparent, light is propagated in straight ines. Of this, in the case of air, we may obtain proof by interening any opaque object between the luminous source and the ye, when the light is at once obscured. Another and better emonstration is to place in line a series of screens, each having small opening in the centre. While in a straight line, light visible to the eye, but if one be moved ever so slightly out f position, it is at once obscured.

As sound and heat radiate from their sources, so light passes ut, or is propagated in radiant lines from a luminous point, herefore, these forms of energy are by some denominated adiant energy.

463. Ray, Pencil, and Beam Defined.—A *luminous ray* is the direction along which light is propagated. In its true mathematical sense it has neither breadth nor thickness. It is the trajectory merely.

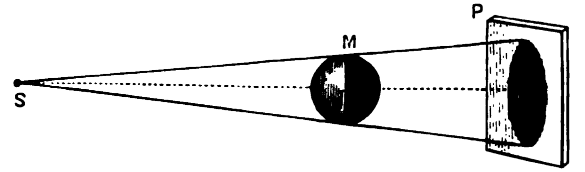
A pencil of light is considered by many to be a portion of the rays issuing from a luminous point; in this form a pencil of light is composed of divergent rays. Others, on the contrary, call any path of light having a measurable section, a pencil; according to this view, it may be made up of either parallel, divergent, or convergent rays.

By a *beam of light*, a pencil of considerable dimensions is indicated; it may be parallel, divergent, or convergent.

464. Shadow and Penumbra.—When an opaque screen is intervened between the ear and a source of sound, there is but slight diminution in intensity; whereas, in the case of a luminous point, the light is completely cut off, and a sharp shadow produced. The cause of this phenomenon is the exceeding shortness of light waves compared with the sound waves. The latter, by virtue of their length, are able to double around a corner, whereas the former pass in straight lines.

In the discussion of the formation of shadows, two conditions are to be considered: 1st. *Where light is emitted from a point.* 2d. *Where it is given off by a body of greater or less dimensions.*

FIG. 189.



Umbra.

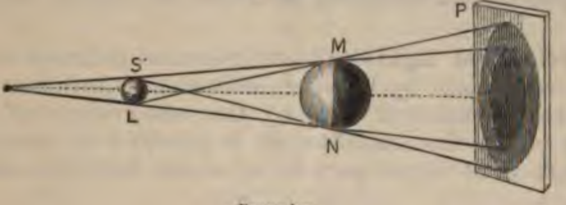
In Fig. 189, S represents a luminous point, and M an opaque body placed in the divergent cone of rays from the point S. The outline of the *shadow* cast under these circumstances upon the screen P will be sharply defined, as shown by the lines drawn from the luminous point to the screen; it is called an *umbra.*

In Fig. 190 the source of light is a sphere represented at S L; the opaque body is at M N. Under these conditions, the shadow differs from the preceding in that it is not separated by a sharply defined limit from the illuminated part of the screen, but between the two there is a dusky ring. To this lighter ring-like shadow, the name of *penumbra* is given. The cause of its production is seen, if we draw lines from the limits of the luminous sphere, past the opaque sphere, to the screen P, Fig.

190. We find that the strong shadow which would be cast by the pencil of light from S, has to contend with that which falls upon the screen from the pencil issuing from L; the shadow is, therefore, diminished in intensity at the margin, and the penumbra formed.

For sake of simplicity, we have in the discussion of shadows, conceived that the rays of light pursue an absolutely straight

FIG. 190.



. Penumbra

line past the opaque body. In actual fact, this is not so, they do undergo a slight deviation from the straight line. Of this, we shall speak at greater length in the discussion of diffraction (607).

465. Images from Small Openings.—If one side of a thin box is removed, and a pinhole made in a remaining side, on placing a candle flame opposite the small aperture, as in Fig. 191, an inverted image of the flame, A B, will be cast on the interior

FIG. 191.

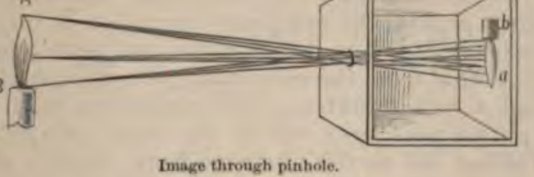


Image through pinhole.

of the side of the box at *a b*, opposite the aperture. The course of the rays and the cause of inversion are also evident.

In the same manner, if a room is made perfectly dark, and a small opening pierced in the shutter, an inverted image of the landscape facing it will be cast upon the side of the room opposite the aperture.

It is not necessary that this should be circular, a triangular opening, or any other shape, will produce the result equally

well, providing it is small enough. Distance lends to the enchantment, for the further away the object the more clearly or sharply is it defined. Of this, as well as the failure of the shape of the opening to affect the image, we have an example in the circular presentations of the sun produced wherever its light has passed through irregular openings between the slats of a shutter and fallen upon the opposite wall. If the wall receives the beam at any other angle than 90°, the form of the image is more or less elliptical. This can readily be corrected, by receiving it upon a book or screen held vertically to its track.

466. Velocity of Light.—The first determination of the velocity of light was made by Roemer, a Danish astronomer, in 1675. The method employed was by the observation of Jupiter's satellites. The first satellite, E, is occulted or passes behind the planet J at equal periods of about forty-two and a half

FIG. 192.

Velocity of light.

hours. When the earth passes from a to b, on the side of its orbit nearest to Jupiter, there is but little difference in its distance from day to day, and, therefore, but little variation between two occultations. When, on the contrary, the earth in its revolution around the sun passes from T to T′ on the opposite side of its orbit, it is found that there has been a total retardation of the actual from the calculated time of occulation of about sixteen and a half minutes. This represents the time required for the light to pass from one to the other side of the earth's orbit. Taking the earth's distance from the sun at 95,000,000 miles, Roemer computed the velocity of light at 190,000 miles per second. At the modern estimate of 91,500,000 miles for the sun's distance from the earth, the rate is 185,500 miles per second.

About fifty years after Roemer's determination, Bradley, an English astronomer, calculated the velocity of light from the aberration or apparent displacement of the stars. He found the rate to be ten thousand times greater than that of the earth in its orbit. Since the latter is about eighteen and a half miles

per second, the velocity of light would be 185,500 miles per second.

In 1849, Fizeau determined the velocity of light by measuring the time required for its transit from Suresnes to Montmartre and back, a distance of 28,334 feet. The apparatus consisted of a toothed wheel capable of varied and rapid rotation. The teeth were of the same width as the spaces between them. The wheel being still, a beam of light was sent from one station to the other, and reflected therefrom by a mirror back to the first position. The wheel then being thrown into revolution, when its rate was sufficiently rapid, the light which passed through an interval between two teeth did not return soon enough to pass through the same interval, but was obstructed by falling upon the projecting tooth. The rate of revolution then being doubled, the light again became visible by passing through the next interval beyond the tooth. The velocity of the wheel, the number of teeth, and the distance between the stations being known, the rate was computed at 196,000 miles per second. Recent experiments by Cornu, made by Fizeau's method and with more perfect instrumental means, gave a velocity of 185,420 miles per second. This agrees closely with the figures obtained from the transit of Venus in 1874.

In 1850, Foucault applied Wheatstone's method by a revolving mirror to the determination of the velocity of light, and obtained the rate of 185,157 miles per second, which is less than that ordinarily assumed, but agrees closely with the recent determinations of the solar parallax. In these experiments the whole apparatus was contained in a small room, and the light traversed a distance of about fourteen feet twice. In one series of trials a tube ten feet in length, filled with pure water, was intervened in the track of the ray, when the velocity was found to be less than in air. This is a most important result of Foucault's experiments, since it is regarded as a crucial test of the undulatory theory that the velocity of light should be less in a more highly refracting medium. The details of Foucault's method may be found in the works of Deschanel and Ganot. Recent determinations by Mr. A. A. Michelson, U. S. Navy, give 186,360 miles per second.

At the rate of 185,500 miles per second, it requires about eight minutes for light to pass from the sun to the earth, about four hours from Neptune, and ten years from one of the nearest fixed stars, 61 Cygni. Stars only visible through the telescope may be so distant as to require thousands of years for their light to pass to our globe. It is possible that in some cases they may have become extinct before it has reached it.

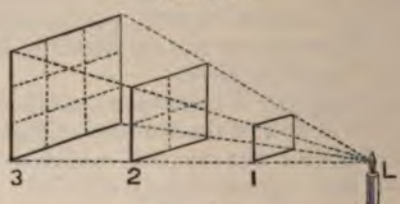
467. Qualities of Light.—Luminous sensations present two characteristics which are generally referred to the rays them-

selves. They are *coloration* and *intensity*. The rays do not possess these properties, but have characters which in their action upon the eye give the appearances in question. The subject of coloration will be dealt with after we have studied the spectrum.

By the intensity of a light we mean its strength or weakness, either on directly viewing it with the eye or in relation to its power to illuminate objects upon which it falls. Various methods have been devised for determining the relative and absolute intensity of different sources of light; their examination constitutes the art of photometry.

468. Laws of Intensity of Light.—The greater the distance between a light and a surface, the less the intensity of illumination. This is a well-known fact within the observation of all, and the law of diminution of intensity may be readily deduced from consideration of Fig. 193. Let 1 2 3 represent three surfaces placed at the relative distances, 1, 2, 3, from a candle flame L, or other source of illumination. The dotted lines represent the course of the radiant lines from a luminous point in the flame, and the relative sizes of the surfaces. The actual amount of light cast upon the three is evidently the same, but in the case of 2 it is spread over a space four times as great as in 1. Its intensity, therefore, in any part must be one-fourth of that on any part of 1. In 3 it is diffused over a surface nine times as great as in 1, therefore, its intensity must be one-ninth. From this we find that *the intensity of light is inversely proportional to the square of the distance from the luminous point.*

Fig. 193.



Intensity of light.

Two luminous bodies at different distances from a surface cannot illuminate the latter with equal intensity unless the further gives out more light, or has greater illuminating power. The intensity of a light at twice the distance being one-fourth, and at thrice one-ninth, it follows that if two flames produce equal illumination of a surface when one is twice as far off as the other, the further must have four times the illuminating power of the nearer; or, if the illumination is equal when the

distances are as one to three, then their illuminating power must be as nine to one. Therefore, *when two sources of light produce equal illumination of two surfaces at different distances therefrom, the illumination powers of the sources of light are in the ratio of the square of their distances from the illuminated surfaces.* The application of this law will be seen in photometry.

We have thus far examined only cases in which light falls perpendicularly. When it falls at an angle, experiment has shown that the law is as follows: *The intensity of illumination when light falls obliquely upon a surface is proportional to the cosine of the angle which the luminous rays make with the normal, or perpendicular to the illuminated surface.*

469. Photometers.—Of these there are a number: 1st. Those acting on the principle of comparing illumination; 2d. Those by comparing the intensity of shadows; and 3d. Those by the relative chemical effects of the flames or sources of light under examination.

Bouguer's photometer is based upon the first principle. It consists of an opalescent or translucent screen of white paper,

FIG. 194.

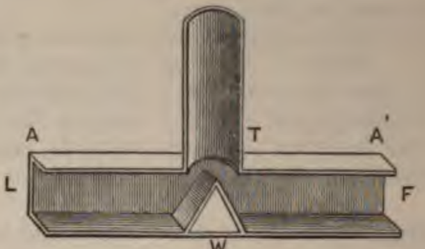
Bouguer's photometer.

ground glass, or thin porcelain, A, divided into two parts by a partition, Fig. 194. The two sources of light are placed on opposite sides of the partition B, and their distances adjusted until the two sides of the screen are equally illuminated. The distances are then measured, when the illuminating power of the lights is as their squares.

A modification of this method is represented in Fig. 195. A A′ is a rectangular box about a foot long, one or two inches square in section, and open at both ends. At T, a tube opens into it. The interior of box and tube are blackened. At the position W, a wedge is placed, the section of which is equilateral; it is covered with white paper. The flames to be examined are then placed opposite the openings L and F, and their distances therefrom adjusted until the eye applied at the upper opening of the tube T, sees the two sides of the wedge equally

illuminated. The distances of the lights from the upper edge are then measured, when the illuminating power is as the square of their distances therefrom.

Fig. 195.

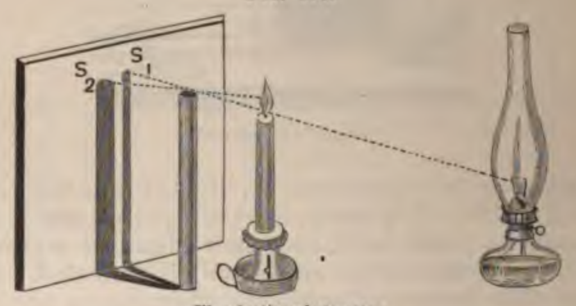


Photometer.

In Bouguer's instrument the partition casts a strong shadow between the illuminated portions of the screen. In a modification made by Foucault, the partition is movable, and by withdrawing it to a greater or less distance, the dark strip may be made to vanish, when the bright portions being exactly contiguous are compared with greater precision.

Rumford's photometer depends upon the second method for its principle of action. An opaque rod is placed at a short distance

Fig. 196.



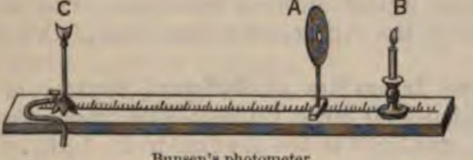
Illumination photometer.

from a screen, the two sources of light are then arranged, as in Fig. 196, so that each forms a shadow of the rod upon it. The lights are then moved until the shadows are of equal intensity. Since that from the lamp is illuminated by the candle, and that from the candle by the lamp, the illumination of the screen by the two sources of light is equal. The intensities of the lights are, therefore, as the squares of their distances from the screen.

Bunsen's photometer acts by the illumination of a spot of grease upon a piece of bibulous paper. It is made with a solution of

spermaceti in naphtha. If a piece of paper, A, Fig. 197, with a grease spot upon it is illuminated by the candle B, placed in front, it appears dark upon a light ground. If by another light, C, from behind, it appears light upon a dark ground. When the flames are adjusted to illuminate it equally, the spot and the rest of the surface show no difference in appearance. This result having been attained, the intensities of the two lights

Fig. 197.



Bunsen's photometer

are as the squares of their distances from the paper. In a recent improvement the thickness of the paper is reduced and the effect of the spot better obtained.

In another photometer devised by Wheatstone, a bead which executes a double system of revolutions is used, a rose-like reflection of the lights compared is thus produced. The details of this are given in Ganot.

Various chemical methods for the measurement of light have been suggested. Among these is the *chlor-hydrogen photometer*, first described by Prof. J. W. Draper, in the "Philosophical Magazine," and afterwards claimed by Bunsen and Roscoe. Another form, in which intensity of light was determined by its power to precipitate gold, is described by me in the "London on Philosophical Magazine" for August, 1859. It is adapted for comparison of sunlight from day to day. In chemical photometers results differ with the reagents employed, according as they are more sensitive to rays of different refrangibility.

In the case of colored lights, Professor Rood has proved, by experiment, the correctness of Grassmann's assumption, "that the total intensity of the mixture of masses of differently colored lights is equal to the sum of the intensities of the separate components." "Am. Journal of Sciences and Arts, vol. xv. page 81.

470. The Candle and other Light Units.—Since a photometer does not measure the quantity of light, but only the relative intensities of two lights under examination, the attempt is made to obtain what may be called quantitative results, by using a standard light for one of the flames under comparison. For ordinary purposes a *standard candle* is employed. "*It is a sperm candle of six to the pound, and burning* 120 *grains per hour*."

When a gas flame is tested against such a standard, the

form or character of the burner, the pressure, temperature, and volume of gas consumed in a given time must all be determined. The value of the gas or other light is then given in terms of candlelight. If, as is the case with an ordinary gas flame, it has an intensity sixteen times that of a single standard candle, it is called a sixteen candle light. In like manner, electric lights are estimated at hundreds or thousands of candle power.

For measurement of lights of feeble intensity, a unit, obtained by heating a platinum wire of definite size in a hydrogen flame produced under uniform conditions, was devised by me, and described in the "Scientific American," Oct. 21, 1871.

471. Relative Intensities of Different Sources of Light.—The electric light from 50 large Bunsen cells, is one-fourth as strong as sunlight. Sunlight is about equal to the light of 5500 candles at a distance of one foot. It is 600,000 times as strong as moonlight, and 16,000,000,000 the strength of that from α Centauri, the third in brilliancy of all the stars.

CHAPTER XIX.

REFLECTION AND MIRRORS.

Law of reflection from polished surfaces—Reflection from unpolished surfaces—Intensity of reflected light—Mirrors and process for silvering them—Images from plane mirrors—Virtual and real images—Multiple images from plane mirrors—Deviation by rotation of mirror—Applications of plane mirrors—Spherical concave mirrors—Principal and conjugate foci—Real and virtual foci—Spherical convex mirrors—Formation of images by spherical mirrors—Spherical aberration and caustics—Parabolic mirrors—Cylindrical mirrors, anamorphosis—Application of curved mirrors.

472. Law of Reflection from Polished Surfaces.—If in the course of a ray of light through a given medium, a second is intervened, certain new phenomena arise. If the second is a transparent, or a translucent body, a portion of the light passes into, or traverses it, but in all cases a greater or less portion, after changing its direction, continues its course in the first medium. To this result the name of reflection is given.

Reflection presents itself under various aspects, according as the surface producing it is more or less perfectly polished. We shall examine the two extreme conditions of perfect polish and

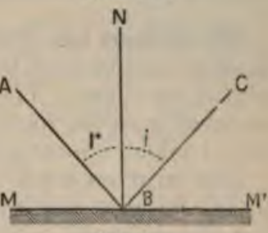
eding irregularity. Between these limits all degrees are ıded.

ı the case of a perfectly burnished regular or specular sur-, the laws for reflection of light are the same as for reflec- of motion, viz.:

t. *The reflected ray A B is in the ≀ determined by the incident ray C B, a normal or perpendicular N drawn e reflecting surface M M′ at the point ıcidence.*

l. *The angle* r *made by the reflected with the normal (angle of reflection) ıal to the angle* i *which the incident nakes with the same normal (angle of ence).*

FIG. 198.



Reflection.

hese laws may be easily demon-:ed by directing a horizontal beam from a projection lantern ı a polished surface, producing conditions as in Fig. 198.

ı reflection from regular or specular surfaces, the object seen ɔt the surface, but an image of the body which is the primary ≀condary source of the light. When, for example, a pencil unlight falls on a mirror in a dark room, the more perfectly light is reflected the less visible is the mirror. *A perfectly hed surface, if it could be made, would be invisible.*

'3. **Reflection from Unpolished Surfaces.**—When a beam of t falls upon an unpolished surface, its rays are reflected in lirections. It is *diffused or scattered.* It was formerly said e irregularly reflected, but this is not the case; it obeys the ı of reflection, but since the surface is composed of project- particles which receive incident rays at all angles, when ɔted they pass off in every direction and the body becomes ɔondary source of luminosity.

is by scattered or diffused light that we are enabled to see determine the position of bodies. When sunlight falls on irror, the eye perceives not its image, but that of the sun. our, or any powder, be dusted on the reflecting surface, ring its polish, or power of regular reflection, as the image he sun diminishes in intensity that of the mirror becomes er marked. By diffusion of sunlight by the air, places which ıot receive direct light are brightened. In this manner, in upper strata of air before sunrise, and after sunset, the ıomenon of twilight is produced.

'4. **Intensity of Reflected Light.**—The power of reflection of ırface and consequent intensity of reflected light varies: with the brilliancy of the original source of light; 2d, with

the perfection of polish; 3d, with the angle formed by the incident ray; 4th, with the nature of the substance—silver, for example, reflects more light than other metals; 5th, the nature of the medium travelled by the ray before and after reflection—polished glass, for example, when immersed in water has its reflecting power seriously impaired.

475. Mirrors and Process for Silvering Them.—Mirrors are defined as bodies with polished surfaces which reflect objects presented to them. The place at which the body appears to be situated is called its image. According to their shape, they are called plane, concave, convex, spherical, parabolic, conical, etc.

The mirrors used by the ancients were made of speculum metal, an alloy of tin, copper, and other metals. Modern looking-glasses were introduced in the 12th century. They are polished plates of glass, coated on the back with an amalgam of tin and mercury. Since pure silver possesses a higher reflecting power than other metals, various processes have been contrived for depositing it on glass. The coating as formed presents a great advantage over the ordinary amalgam in that it may be polished and used as a true specular surface. When so burnished either side may be employed.

The method I have generally employed, and with excellent results, is known as the Rochelle salt or Cimeg's process.

476. Images from Plane Mirrors.—The effect of a plane mirror, as is well known, is to produce behind it images which accurately represent in size and form the objects in front. This result may be explained according to the laws of reflection.

In the figure a divergent pencil of light proceeds from a luminous point at the top of a candle flame A, and is reflected from the mirror at B. After reflection the rays on entering the eye have the same divergence as when they impinged upon the mirror, and if produced backwards meet at a point C, which is the position of the image of the top of the flame. In like manner, every point appears in its proper position, and a complete image is observed.

FIG. 199.

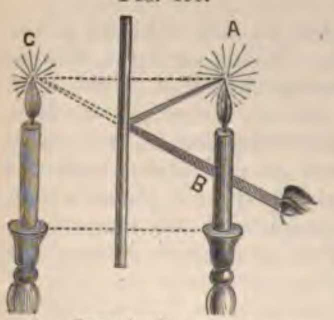


Image in plane mirror.

The images produced by plane mirrors are *erect images*, but they are not exact duplicates of the objects, since they differ from them exactly as the right hand differs from the left. This may be readily seen, if we examine the reflected image of a page of print in a mirror, when it appears

as when viewed through the back of the page, or like the surface of the type from which it was printed.

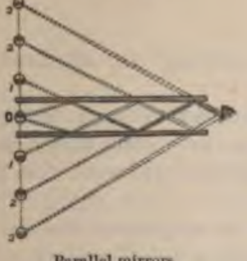
477. Virtual and Real Images.—According as rays are divergent or convergent after reflection, so do the images differ. In the experiment represented in the preceding article, the rays after leaving the reflected surface, enter the eye as a divergent pencil; if, however, they are supposed to be projected through the mirror they meet at a point. The eye is then affected as though the rays proceeded from this point; and though seen, there is no real image formed. Rays do not come from the other side of the mirror. These are called *virtual images.*

When, on the contrary, the rays converge after reflection, as in concave mirrors, they do meet in front of the mirror, on the same side as the object, and when received upon a screen properly placed, a real image is formed. These facts may be concisely stated as follows: *Real images are produced by the reflected rays themselves; virtual images by their prolongation backwards.*

478. Multiple Images from Plane Mirrors.—While metallic or specular mirrors give a single image, ordinary glass mirrors give a series, as may be seen by examining the reflection of a candle flame in an oblique line in a looking-glass. Images of different intensities viewed under these circumstances result from reflections from the anterior and posterior surfaces of the glass, and from secondary reflections from one to the other.

If an object, O, be placed between two parallel mirrors, and viewed as delineated in Fig. 200, a great number of images are

FIG. 200.



Parallel mirrors.

FIG. 201.

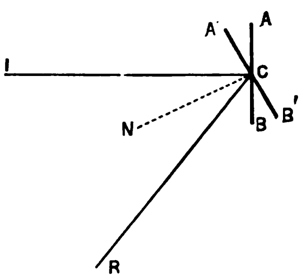
Lateral inversion of image.

perceived, of which a few only are shown. Theoretically the number should be infinite, but since in practice a portion of light is lost at each reflection, they become dimmer and dimmer, and finally disappear. If the surfaces are true and exactly parallel, they will be arranged in a straight line, as in the figure. But,

if inclined at an angle, they appear to be on the circumference of a circle. Practical application of this fact has been made in the parallel adjustment of mirrors. If two plane reflectors are placed at right angles to each other as S S_2, Fig. 201, three images of the object are produced; if the angle be made more and more acute, the number becomes greater and greater, and when parallel they are theoretically infinite, as stated above. Upon this principle of multiplication of images the kaleidoscope depends for its action.

479. Deviation by Rotation of Mirror.—In Fig. 202, A B represents the edge of a plane mirror receiving the incident ray I C perpendicularly. The ray will then be reflected back along the line I C. Let the mirror be turned or rotated about an axis passing through its face at the point C, until its edge assumes the position A′ B′, and forms the angle A′ C A, with its first position. The reflected ray will then pass off in the line C R, making with the normal, C N, an angle, N C R, which is equal to N C I, the angle of incidence. The total deviation of the reflected ray is, therefore, double the angle I C N or A C A′, through which the mirror has been turned. The same will be found for any other amount of rotation. It, therefore, follows that: *When a plane mirror is rotated in the plane of incidence, the direction of the reflected ray is changed by double the angle through which the mirror is turned.*

FIG. 202.



Effect of rotating mirror.

480. Applications of Plane Mirrors.—Among the applications of plane mirrors are:

1st. For toilet purposes, this has come down from the most ancient times. Two or more mirrors are sometimes used, enabling a person to examine the back and sides of the head and figure.

2d. In drawing rooms, to increase the apparent size of the apartment, and multiply the objects therein by repeated reflections.

3d. By physicians, in the *laryngoscope*, for examination of the larynx or other cavities not easily reached by direct vision; and by dentists, for examination of the posterior surface of teeth. In the *endoscope* a plane mirror is applied to examination of the urethral canal.

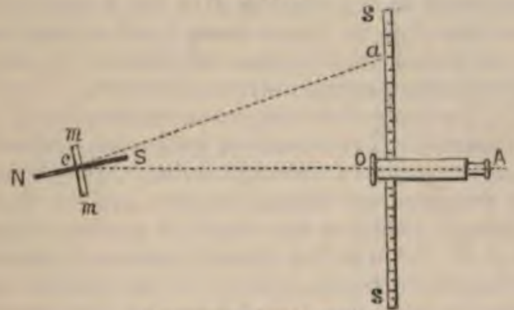
4th. In the *microscope*, to direct the light along the axis of the instrument.

5th. In the *heliostat*, the use of which is to keep a beam of sunlight permanently in a straight line; the result is obtained by driving a plane mirror by clockwork, in a manner to produce the desired result. Among heliostats, an excellent one is that of Pragmoski. Such an apparatus is absolutely necessary for microscope photography by sunlight.

6th. *Mance's heliograph* is an instrument for giving signals at great distances by flashes of sunlight produced by a mirror. The system consists in giving flashes to the right and left. From these an alphabet is made up, as in the Morse telegraphic system of dots and dashes. In this way messages at the rate of twelve words per minute have been sent to a distance of forty miles in fine weather.

7th. The *measurement of small angles*, as in the deflection of magnetic needles, is often made to the best advantage by the use of a mirror, as represented in the figure. The observing telescope A O is attached to a scale *s s*, the axis of the instrument

FIG. 203.



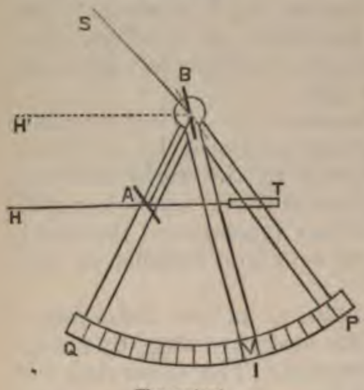
Measurement of small angles.

corresponding to zero of the scale. At N S a magnet is suspended, bearing a mirror *m m*, arranged with its plane perpendicular to the axis of the magnet N S.

The apparatus is adjusted to have the zero of the scale appear on the cross wires of the telescope. When by any cause the magnet and its mirror are deflected, the image of some other figure on the scale appears. Suppose, for example, the figure at *a* represents the angle *a c* O, and it appears, then the actual deflection of the magnetic needle is one-half of this angle, according to the principle laid down in the article on deviation. In the *goniometer*, an instrument employed for the measurement of the angles of crystals, the principle of reflection is also employed.

8th. The *sextant* or *quadrant*, invented by Newton and re-invented by Hadley, is another example of the application of this method, together with that of transparent or semi-transparent mirrors.

FIG. 204.



The sextant.

The essential parts of the instrument are a plane glass mirror partially silvered and fixed to the frame at A, Fig. 204. This not only reflects light received in the direction A B, but also enables the observer to see objects in the line A H through the telescope T, which is also stationary. A second mirror, B, is mounted on the axis of the pointer I, which traverses the graduated arc Q P. When they are parallel to each other, the index is at P, the zero of the scale, the incident ray H′ B, parallel to H A, will, when it falls on B, be reflected along the line B A to A, and thence along A T to the observer at the telescope, who thus sees by two reflections, at B and A, the same objects at H that he views directly through the partially silvered mirror.

Suppose it be desired to determine the altitude of the sun above the horizon. The observer holds the sextant in such a manner that the rays of sunlight falling upon B are reflected to A, and produce an image in the eye at T. He then moves the arm I, until this sun image is made to appear on the horizon, as at H, through the partially silvered mirror A. The number of degrees through which the arm I has been moved over the scale to cause the coincidence of the images S and H is then read off. According to the preceding section on deviation by mirrors, this is double the angle that S and H actually form with each other; one-half the angle obtained, therefore, represents the angular height of the sun above the horizon.

In practice the sextant is graduated to half degrees, which are valued in the enumeration as whole degrees. The correction mentioned is thus avoided, and the true result obtained by the actual reading. In addition to this device others, as dark glasses to reduce the brightness of the sun's image, and a vernier, and reading microscope, in place of the pointer I, are employed.

9th. In the determination of the altitude of a star, it is often difficult to fix the position of the true horizon. This is surmounted by a device known as the *artificial horizon*. A telescope provided with cross lines is mounted on a horizontal axis, to

traverse a vertical circle which is carefully graduated. The instrument is turned to the star, and the position of the telescope read off on the circle. A cup containing mercury is then placed in front of the apparatus, and the reflected image of the star viewed therein, and brought upon the cross lines. The new position is then read off, when half the angle included between the two positions represents angle of altitude of the star above the horizon.

10th. The device of a *transparent mirror* is sometimes resorted to in theatrical representations. A large mirror of unsilvered glass is placed at a suitable angle upon the stage, which is dimly lighted. Through this sheet of glass the audience sees everything upon the stage. Beneath, in such a position that it may be reflected to the audience, is the ghost or other object, brilliantly illuminated. As this moves about, it appears, from the auditorium, to pass among the things and actors upon the stage. Thus the deception of the ghost in the play of Hamlet is produced. By other and suitable arrangements, the illusions of the magic cabinet and disembodied head are accomplished.

11th. The *kaleidoscope* invented by Sir David Brewster, and now used in the arts of design, is another application of reflecting property of mirrors. It consists of a tube in which two glass mirrors are inclined at an angle of sixty degrees to each other, and extending along its whole length. One end is closed, excepting a small hole in the centre, to which the eye is applied. The other is provided with two plates the outermost of ground glass. Between these a number of pieces of colored glass are placed. Directing the tube to the sky or other source of light, and revolving it while looking through the eye-hole, the pieces of colored glass as they fall into new positions form symmetrical patterns which are very beautiful.

By the introduction of a third glass mirror, thus forming a combination the section of which represents an equilateral triangle, effects equal to three simple kaleidoscopes are produced.

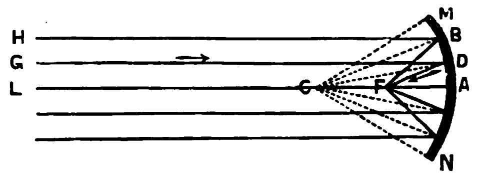
481. Spherical Concave Mirrors.—In a spherical mirror, as the term indicates, the reflecting surface is a portion of a sphere; if formed by the interior, it is called a *concave;* if by the exterior, a *convex* mirror.

In Fig. 205, a concave spherical mirror is shown in section. The distances, C A, C M, C N, etc., represent the radii upon which it has been constructed, they are, therefore, called the *radii of curvature*. To the point C, the terms *centre of curvature* and *geometrical centre* are applied. The radius of curvature C A is called the *principal axis*. All other radii or lines passing through C, and touching the surface of the mirror are called

secondary axes. The point A, at which the principal axis touches the mirror is called the *pole.* The angle M C N, included between the extreme radii of curvature is the *aperture.* A section made by cutting it by a plane containing its principal axis is called a *principal* or *meridional section.* The section, Fig. 205, is of this description.

The laws governing the action of spherical, are the same as for plane mirrors; the former is made up of an infinite number

FIG. 205.



Focus of spherical concave mirror.

of plane surfaces, called *elements.* A normal to the curvature at any point is a perpendicular to the element at that point. Since all normals to the surface of a sphere pass through its centre of curvature, one may be readily constructed.

482. Principal and Conjugate Foci.—Applying the principles laid down in the last paragraph to Fig. 205, let C B be a normal to a point on the surface of the mirror, and H B an incident ray to the same point; it will be reflected on the opposite side of the normal, and the angles H B C and C B F will be equal.

In the case under consideration the incident ray H B is parallel to the principal axis. Take another ray, G D, also parallel to the principal axis; it obeys the law of reflection, and following the line D F cuts it at the same point as B F. In like manner, every incident ray parallel to the principal axis after reflection from a concave mirror of less aperture than ten degrees crosses it at F. The point of meeting of the rays in F, is, therefore, called the *principal focus.*

Rays falling upon a mirror may be made to meet at other positions than that represented; therefore, foci receive special designations according to the manner produced.

Where rays are parallel to the principal axis, it is formed upon that axis, and is called the principal focus. *The distance,* A F, *of the principal focus from the surface of curvature is one-half of the radius of curvature.* This distance is also called the *principal focal distance* of the mirror.

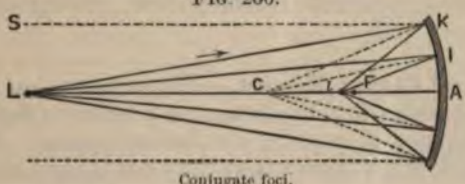
Where rays are divergent, as from a luminous point, a brief application of the laws of reflection shows that their divergence will be diminished, but the character of the reflected

ncil and position of the focus will vary greatly, according to the sition of the luminous point. Three cases may be examined.

1st. When the point whence divergent rays issue is at the cus of the mirror, Fig. 205, the reflected rays will be parallel, r this is simply a reversal of the process by which parallel ays were converged. If it is desired to produce a beam of arallel rays, it may be obtained by placing the source of light at the focus of a concave mirror.

2d. If the luminous point L be moved along the principal axis to a point between the principal focus F and the centre of curvature C, the reflected rays L K and L I will meet beyond the centre of curvature at L. Conversely, rays from a luminous point at L will converge at l within the centre of curvature. Since these two positions bear this mutual relation to each

FIG. 206.

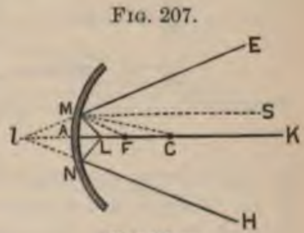


Conjugate foci.

other, they are called *conjugate foci*. If the luminous point is at the centre of curvature, since the rays are then normal to the surface of curvature C, they will be reflected back upon it, and the conjugate foci are in this case identical. In all cases where a concave mirror converges rays, the rays are divergent after they pass the focal point. *From a beam of parallel rays, therefore, a convergent or a divergent pencil of light may be obtained by a concave mirror.*

If the luminous point be passed nearer to the mirror than its focal distance, though the divergence of the rays is diminished, they retain this character and do not come to a true focus. This state of affairs is shown in Fig. 207, L being the luminous point between the focus F and the surface of the mirror A, the incident rays L M and L N are reflected in the paths M E and N H, which are divergent.

FIG. 207.



Virtual focus.

483. Real and Virtual Foci.—In the first and second conditions studied in the preceding article, if a small screen, as a piece of white paper, be placed at the focus, an image of the object is formed. In the first case, the sun or the moon being the source of light

the rays are practically parallel, and an image of either of these objects will be formed on the screen at the principal focus. In this manner the principal focus for any mirror may be determined; its distance multiplied by two gives the radius of curvature. In the case of conjugate foci, an image of a candle flame or other luminous object will be formed at one focus, the object being at the other. The actual image formed upon the screen under these conditions, is called a *real focus.*

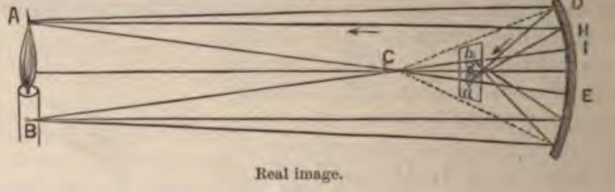
In the third case in the preceding article, the reflected rays are divergent, and there is no real focus, but if we imagine these divergent reflected rays, M E, and N H, Fig. 207, to be prolonged backwards through the mirror in the directions M l, and N l, they meet at the point l. To this point the name of *virtual focus* is given. As in the case of virtual images formed by plane mirrors, we may, therefore, say, *that a real focus is formed by the reflected rays themselves; a virtual focus, by their prolongation through the mirror.*

484. Spherical Convex Mirrors.—These have but few practical applications besides that of obtaining a point of light, or increasing the divergence of rays in a reflected beam. Application of the laws of reflection shows that they can only have virtual foci.

485. Formation of Images by Spherical Mirrors.—From consideration of the image of a luminous point we pass to that of any object possessing appreciable size. Where a mirror is concave, two cases present themselves: 1st, the image is real; 2d, it is virtual

Let A B, Fig. 208, represent the object placed beyond the centre C. To determine the focus of the point A, draw thence

Fig. 208.



Real image.

to the mirror the secondary axis A E, and also an incident ray A D. Construct a normal to D, and draw the reflected ray D a, taking care that the angle of reflection C D a is equal to the angle of incidence A D C. At the point a, where the reflected ray cuts the secondary axis A E, the image of the point A, will be formed, the same being its conjugate focus. In like manner, draw an incident ray and secondary axis from B, when it will be

found that after reflection the former cuts the latter at b, where the image of B appears at its conjugate focus. All points of the objects A B may thus be examined, when it will be found that their conjugate foci lie between a and b. It, therefore, follows, that *the image of the object* A B *placed beyond the centre of curvature is formed at a b, between the centre of curvature and the principal focus; it is also real, inverted, and smaller than the object.*

If the object is at a b, between the principal focus and the centre, the reverse conditions are presented, and the image is formed at A B. It is *real, inverted, larger than the object, its size increasing as the object is placed nearer to the principal focus.*

When it is at the principal focus, the reflected rays from each point being parallel to the secondary axis drawn therefrom, *an image is not formed.*

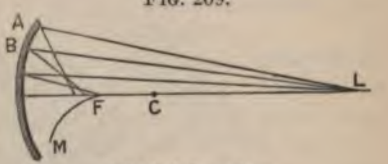
When it is between the mirror and its principal focus, the rays do not come to a focus, but are divergent; a real image, therefore, is not formed, but the eye, when properly placed, perceives one which is *virtual, erect, and larger than the object.*

By placing one's self in front of a concave mirror, all these facts may be verified. At a certain distance, a real inverted smaller image is seen, on approaching this becomes confused, and when at the focus it disappears; passing within the focus an enlarged virtual erect image appears.

In the case of convex mirrors only virtual images are produced. At any position before these the image is always erect, and smaller than the object, as can be shown by direct experiment, or by the construction of a diagram, as with concave mirrors.

486. Spherical Aberration and Caustics.—The statements thus far made regarding mirrors, are only correct while the angle of aperture is not more than ten degrees. When it passes beyond this, the rays reflected from the exterior portions reach a focus nearer to the mirror than those reflected from the regions about the pole, as at B, the image is, therefore, blurred. To this effect and its cause the term *spherical aberration* is applied. It is represented, Fig. 209, where the ray from L, reflected from A, cuts the principal axis within the point at which the ray reflected from B reaches it. By connecting the points of intersection, the curve M F is obtained. This is called the *caustic*. It is perceivable when lamp or candle light is reflected from the interior of a tumbler upon milk or other fluid contained therein.

FIG. 209.

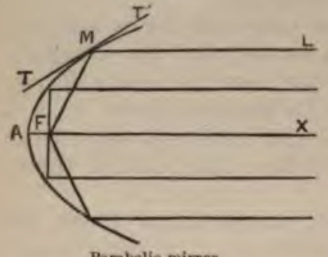


Spherical aberration.

487. Parabolic Mirrors.—To avoid the aberration in spherical mirrors of aperture greater than ten degrees, a parabolic curvature is employed.

In Fig. 210, conceive that the arc A M of a parabola is caused to revolve about its axis A X, a mirror of the form in question would result. The figure also indicates that in a parabola any straight line, F M, drawn from the focus to any point, M, and there meeting a line, M L, parallel to the axis will form equal angles with a tangent, T T′, to the curve at their point of intersection, M. From this it follows, that all rays parallel to the axis will be reflected to the focus; and, conversely, a luminous point at the focus will give parallel rays. Hence the use of these in railway and carriage reflectors.

Fig. 210.



Parabolic mirror.

488. Cylindrical Mirrors. Anamorphosis.—The distortion by convex mirrors of this form is very great. When the axis is vertical, it acts like a plane mirror, as regards the angular magnitude under which height of the image is seen, and like a

Fig. 211.

Anamorphosis.

spherical in relation to its breadth. The reflected image is, therefore, greatly contracted in its horizontal dimensions.

By drawing pictures with the proper distortions, and viewing them by reflection in a cylindrical mirror, as in Fig. 211, the confused appearance existing is corrected, and the image represents a recognizable form. This method of restoration of true proportion is called *anamorphosis.*

Concave cylindrical and tubular mirrors are used in examination of different cavities of the body. They serve to direct light into such cavities. They vary in form and size according to the use for which they are applied. Among these are the *aural speculum; nasal, or rhinoscope;* also *rectal, vaginal,* and *urethral specula.*

489. Applications of Curved Mirrors are chiefly for condensing light, and for use in reflecting telescopes.

In many forms of *microscope*, a concave mirror is attached to the posterior face of the plane mirror, which reflects the light through the stage of the instrument. By either of these direct or oblique illumination is obtained as desired.

The *ophthalmoscope* consists of a concave silvered mirror with an aperture through the pole. It is used to direct a convergent beam of light into the eye under examination. The interior thus illuminated is viewed by the operator placing his eye at the aperture. The inspection can be conducted with or without the aid of magnifying glasses.

In the *laryngoscope*, already mentioned (480, 3d), a mirror such as that described, is used in conjunction with a plane reflector. The latter is held by a handle at a suitable angle at the back part of the mouth, the condensed light from the ophthalmoscope mirror is thus reflected into the larynx, the plane reflector serving to direct the light into the organ, and enable the operator to view its interior.

In the *Lieberkühn* objective for microscopes, the glass objective is placed in the pole of a reflecting mirror, opaque objects are thus subjected to a more brilliant illumination (584).

In reflecting telescopes concave mirrors are employed to produce images of celestial and terrestrial objects. These are also called *catoptric telescopes.* Various forms have been constructed. In the *Herschelian telescope* the reflector is set at a slight angle to the tube, and the image is produced at one side near the mouth, and there viewed directly by the eye of the observer. In the *Newtonian reflector* it is set at right angles to the tube. In the axis of this near its mouth, a plane mirror reflects the converging beam to one side whence it passes through an aperture and is viewed by the eye. In the *Gregorian* form it is perforated through its pole; the rays, as in the Newtonian,

are received upon a plane mirror, which is set parallel to the concave mirror; the converging beam is, therefore, sent back to the aperture in the centre of the concave mirror, and there viewed by the eye.

By the process for silvering glass, telescope and other mirrors are now made of this substance and covered with pure silver. Accurate curvature, high reflecting power, and lightness are thereby obtained.

CHAPTER XX.

REFRACTION AND PRISMS.

Refraction illustrated—Refraction power of different media—Laws of single refraction—Index of refraction—Critical angle. Total reflection—Atmospheric refraction and mirage—Media with parallel surfaces—The prism—Track of ray in prism. Angle of deviation—Minimum deviation—Reflecting prisms.

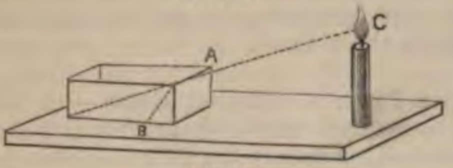
490. Refraction Illustrated.—Much of the light falling upon a surface is reflected; the quantity so disposed of is greater as the color of the body is lighter and its polish more perfect. Even the whitest and most accurately polished surfaces do not reflect the whole of the incident light, but a portion always penetrates the substance. In opaque bodies the whole is absorbed very near the surface. In those which are translucent it is taken up slowly, and a portion may pass out from the opposite side if the medium is not too thick. In those highly transparent, a small portion is reflected, the greater part passing through with but slight loss.

In the passage of a ray of light from one transparent medium, *air*, to another, *water*, the track does not undergo any change of direction, providing it enters the second perpendicularly. If, on the contrary, it penetrates it in any other course than the *normal* or perpendicular, it no longer follows the same track, but suddenly breaks therefrom at the surface, and pursues a straight line in a different direction. To this phenomenon the term *refraction* is applied.

The direction in which the course of a ray is broken differs with the relative densities of the two media concerned. Of this the following experiments are illustrations. Let A B represent a rectangular aquarium with the vertical end A covered by a board, or blackened to render it opaque. At C a candle flame

is placed, the rays therefrom being obstructed by the opaque side only illuminate the upper part of the aquarium, and the whole of the bottom is in deep shade when observed from the side as in Fig. 212. Now let the tank be slowly filled with

FIG. 212.



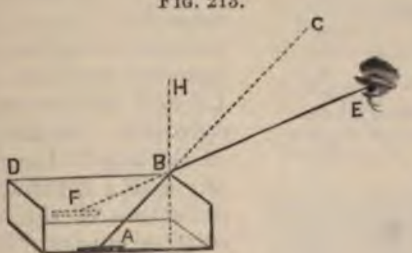
Refraction.

water; then viewing it as before, as the fluid rises higher and higher, more and more of the bottom is illuminated, until when full to the brim the rays reach as far forward as B.

In the latter case the light has passed from a light medium, *air*, into a denser medium, *water*. It has also impinged upon the surface of the latter at a considerable angle to the normal. It has consequently been refracted from the course C A, into A B, the new track being bent towards the side of the tank at which the ray entered. Viewing that side as a perpendicular in the medium to its surface, we say that the refraction is towards the perpendicular or normal. The plane separating the two media is called the *refracting surface*, and each of the media a *refracting medium*.

Empty the tank and place a silver coin, A, upon its bottom, so the eye at C can see it in a straight line, then move to E;

FIG. 213.



Refraction in tank.

here the coin is invisible on account of the intervention of the opaque side B. Filling the vessel with water, the position of the eye not changing, it again comes into view, and together with the bottom appears to rise, so that the vessel seems to be shallower than before.

These appearances are all due to refraction. The ray A B

proceeding from the coin takes the direction A C when the tank is filled with air; but when with water, the ray A B, on leaving the surface at B, undergoes refraction, and takes the new course B E, the eye perceiving A as though at F. If we compare the new or refracted path B E, and its preceding path B C, with the normal H G, we find that in passing from the dense into the light medium, the ray has been refracted from, instead of towards the normal.

491. Refraction Power of Different Media.—In the experiment with the coin, the course of the emergent or refracted ray was bent away from the normal at the point of emergence. In the trial with a candle it was bent towards the normal. In this, as in all cases of refraction, the medium in which the ray makes the smaller angle with the normal is said to have the greater refractive power.

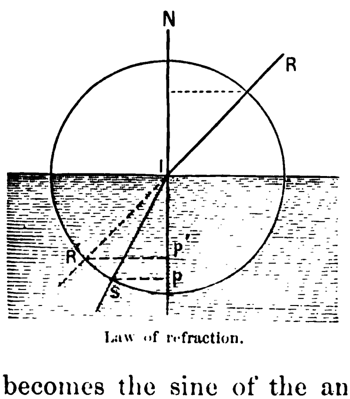
Though generally this is true, it is not always so. In place, therefore, of speaking of the *denser* and *rarer medium*, it is more accurate to use the terms *more refractive* and *less refractive*.

In gases, liquids, glass, and uncrystallized media, the refraction is single. In many crystalline bodies, as Iceland spar and selenite, on the contrary, the refracted ray is divided. This is called double refraction.

492. Laws of Single Refraction.—These were first stated by Snell, and afterwards enunciated by Descartes. They are generally known as the laws of Descartes, or as the *law of sines*.

Let I, Fig. 214, represent the point of impact of the ray R upon the surface separating two media, and I S its refracted course in the second. The angle made by R I or R′ I, and the normal to the surface, is the *angle of incidence*, and the angle made by I S and the normal, is the *angle of refraction*. Continuing the course of the ray R I to R′ we have the angle R′ I S formed, which is the deflection of the ray R I from its original course. This is called the *angle of deviation*.

FIG. 214.



Law of refraction.

Describe a circle around I as a centre, and from S let a perpendicular fall on the normal, it will cut it at P. The line S P then becomes the sine of the angle of refraction S I P. From R′, the point of intersection of the prolonged incident ray and the circumference of the circle, draw a second perpendicular to the

normal, it will intersect it at P′, and the line R′ P′ will represent the sine of the angle of incidence. As one of these sines varies, the other changes in a constant ratio. From these facts we have the following laws.

1st. *The refracted and incident rays are in the same plane, and at right angles to the surface between the two media.*

2d. *For all angles of the incident ray, the ratio of the sine of the angle of incidence and of the sine of the angle of refraction is constant for two given media, but varies for different media.*

493. Index of Refraction.—The ratio between the sines of the angles of incidence and refraction is called the *index of refraction.* It varies with different media. From air to water it is $\frac{4}{3}$; from air to glass it is $\frac{3}{2}$. If the course of the ray is considered in the opposite direction, the index is reversed, being from water to air $\frac{3}{4}$, and from glass to air $\frac{2}{3}$.

When a ray passes from a vacuum into a medium, the ratio is greater than unity, and is called the *absolute index of refraction* or simply the index for the medium in question. In air, the absolute index is so small that it may be neglected when compared with liquids and solids.

INDICES OF REFRACTION.

For solids and liquids.

Diamond	2.47 to 2.75	Oil of turpentine, sp. gr. 0.885	1.478
Phosphorus	2.224	Alcohol	1.372
Sulphur	2.115	Albumen	1.360
Sapphire	1.794	Ether	1.358
Ruby	1.779	Crystalline lens, outer layers	1.337
Carbon bisulphide	1.678	Crystalline lens, inner layers	1.379
Iceland spar, ordinary ray	1.654	Crystalline lens, central	1.400
Iceland spar, extraordinary	1.483	Sea water,	1.343
Flint glass	1.575 to 1.642	Vitreous humor	1.339
Rock salt	1.545 to 1.550	Aqueous humor	1.337
Rock crystal	1.548	Pure water	1.336
Plate glass, St. Gobin	1.543	Ice	1.310
Crown glass	1.531 to 1.563		
Linseed oil, sp. gr. 0.932	1.482		

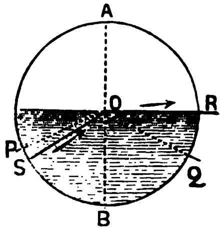
Gases at 0° C. and 760 mm. pressure.		*Refractive indices of gases.*	
Vacuum	1.000000	Carbonic acid	1.000449
Hydrogen	1.000138	Hydrochloric acid	1.000449
Oxygen	1.000272	Nitrous oxide	1.000503
Air	1.000294	Sulphurous acid	1.000665
Nitrogen	1.000300	Olefiant gas	1.000678
Ammonia	1.000385	Chlorine	1.000772

The relative index of refraction from any medium, A, into a second, B, is always equal to the absolute index of B divided by the absolute index of A.

494. Critical Angle. Total Reflection.—Consideration of the law of sines shows, that if the incident ray is in the less refractive medium, there is always a corresponding angle of refraction. This is not the case when the incident ray is in the more refracting medium. When it passes from water into air, for example, there is an angle at which the angle of refraction becomes 90°; beyond this the ray is *totally reflected* at the surface.

In Fig. 215, let S O be a ray of light traversing water from S to O, and suppose that at O it is refracted in the direction O R. Any ray, P O, making a greater angle with the normal than the angle S O B, cannot emerge, but will of necessity undergo reflection at O, and follow the direction O Q. The angle S O B being the limit at which the refracted ray can emerge from the fluid, is the *critical angle.* From water to air this is 48° 35′; from glass to air, 41° 48′.

FIG. 215.

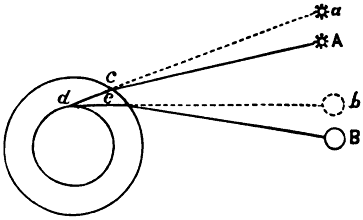


Critical angle.

Examples of total reflection are seen in the brilliancy of the surface of bubbles of air in water, when viewed at a certain angle. If a plain glass tumbler, or a beaker, is filled with water, and held above the head, until the line of vision is through the side of the vessel to the surface, as it is raised, an angle is soon reached at which objects on the ground appear, their images being produced by total reflection from the under surface of the liquid.

495. Atmospheric Refraction and Mirage.—As light is refracted on its exit from air to water, it likewise changes its course on passing from vacuous space into the atmosphere. Consequently only those celestial bodies actually overhead appear in their true

FIG. 216.



Twilight.

position, since their rays enter the air at the normal. The light from a star at A, Fig. 216, is refracted on entering the air at *c*, and the observer at *d* sees it as though at *a*. At B, the sun is represented after it has passed below the horizon; its light is refracted as it enters the air at *e*, and the observer at *d* sees it as

though at b. Light from the sun is, therefore, brought to us by refraction as twilight after that luminary has disappeared below the real horizon. The same happens in early morning, and he appears before the horizon has actually been reached. Thus the day is lengthened a little morning and evening.

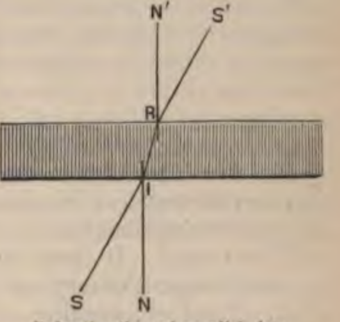
In the figure the lines $d\ c\ d\ e$ are drawn as though straight. This is not actually the case. The layers of air nearest the earth are the densest, consequently the refraction there is greatest, and the light follows a curved course.

Since some objects on the earth's surface absorb the sun's rays more readily than others, they are, consequently, warmer. From their surfaces upward currents of heated gas are rising. These being lighter than other portions of air, have a different refractive power; in addition, they are continually in motion; and so media of variable powers of refraction are continually passing between the eye and distant objects. The result is continual change in positions, which gives to them the appearance of dancing. The same effect is caused when we view anything through air rising from the surface of a hot stove.

In the phenomenon known as *mirage*, inverted images of distant objects appear to travellers on deserts, as though reflected from a surface of tranquil water. The explanation of this, as given by Dr. Arnott, is as follows: "The strata of air immediately above the heated sandy soil, are greatly expanded and rarer than the strata above them, which, in spite of the law of diffusion, remain denser. Rays of light proceeding from objects in a direction a little above the level of the earth, and nearly parallel to it, meet the heated and rarer strata at a very obtuse angle. They take the course of a curve as the result of gradual refraction, until at length the angle of incidence, which goes on increasing, reaches the point at which refraction is changed into reflection, and the rays meet the eye of the spectator as if proceeding from an object below the level of the earth. This gives to it the appearance as if it was reflected from the surface of water."

Mirage effects are not confined to hot climates, they have been noticed by Arctic navigators at high latitudes.

Fig. 217.



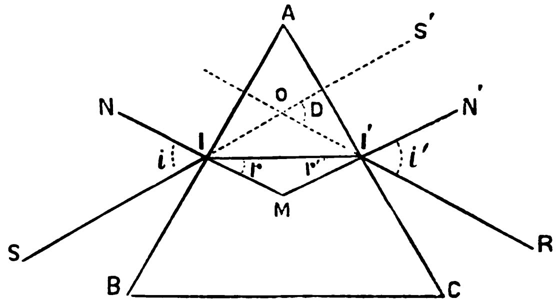
Refraction through parallel plate.

496. Media with Parallel Surfaces.—When a ray impinges at a right angle, N I, upon a medium, the surfaces of which are parallel, it passes through without change of direction. If at an angle, as S I, it is bent towards N I on

entering; and on emerging into the less refractive substance, it is bent from the normal N′, and the emergent ray R S′ is parallel to the continued incident ray S I.

497. The Prism can be made of any solid or liquid substance which is transparent. The material usually employed is glass, but liquids possessing great refractive power, as bisulphide of carbon, are frequently used. The form generally adopted is that of a wedge, or column, a section of which is an equilateral triangle, as at A B C, Fig. 218. In such sections A is spoken

FIG. 218.



of as the *summit or apex*, and B C the base. The line of meeting, A, of the two faces represented edgewise at A B and A C, is called the *edge*. Any section perpendicular to this is called a *principal section*. If perpendiculars be drawn from each side to the opposite angle of the triangle, forming a principal section of an equilateral prism, they all meet at a point called its centre. A line drawn through this perpendicularly to a principal section, is its *axis*. When a fluid is used, a cell of the form in question, made of clear glass, is filled therewith.

From a purely optical point of view, only the two plane faces forming the edge are considered. The angle embraced between these is called the *refracting angle*. An equilateral prism is, therefore, called a prism of sixty degrees, since that is its refracting angle.

498. Track of Ray in Prism. Angle of Deviation.—With variation in the angle of incidence, made by the ray and the surface of the prism upon which it impinges, the track through the prism will also vary. It may be made to undergo reflection at the second face, and emerge at the third. To avoid ambiguity we shall, therefore, confine our explanation to what takes place when it is in the best position.

In Fig. 218, A B C represents a principal section of a prism of sixty degrees, S I is an incident ray falling upon the face

A B, and making the angle of incidence S I N with the normal N. Passing from air into glass, it is bent towards the normal I M, drawn therein, and the angle of refraction r is less than the angle of incidence i. Impinging upon the opposite face A C, it is again refracted on emerging, and follows the direction R, and the angle of refraction i' is greater than the angle of incidence r', according to the law for passing from a highly refracting medium to one of less power.

If the incident light S I is a beam of sunlight, while the prism does not interfere, the image is produced at S′, the prolongation of S I. When the prism is intervened and properly adjusted, the light on emerging takes the direction R. It has been changed or deviated from its course. To measure the extent of this, the line of refraction R is prolonged until it intersects the line of incidence S S′ at O, when the angle D represents the *angle of deviation.*

From this it is obvious that a ray of light in its passage through a prism is deviated or deflected towards its base.

499. Minimum Deviation.—Suppose a beam of sunlight be directed across a room by the mirror of a heliostat, it forms a spot of light or image of the sun on the opposite wall. If it is caught upon an equilateral prism, held with its axis vertical, and rotated thereon, the spot of white light will disappear, and in its place a colored elongated image is produced. The direction in which this is formed shows that the light on emerging from the prism is deviated towards its base.

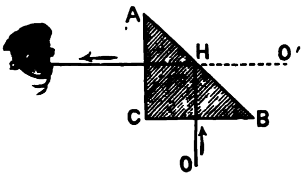
Rotating the prism upon its axis, the angle of incidence diminishes, the colored image moving along the wall nearer to the original location of the spot. Continuing the rotation, a point is finally reached at which the image begins to recede from this position. There is, therefore, a particular angle of deviation at which the colored image is nearest to the original line of light from the heliostat mirror. This deviation being less than in any other case, it is called the angle of *minimum deviation.* It is to this angle that a prism must be set when used for spectrum work.

In Fig. 218, the prism is shown in its position of minimum deviation. The slightest rotation upon its axis, to right or left, causes the image to undergo greater deviation, and approach C. It will be noticed that the angles of incidence i and emergence i', under the adjustment of minimum deviation, are equal.

Since rays of different colors vary as regards their refrangibility, it is necessary to set the prism for the minimum deviation of the ray in which work is done, when great accuracy is desired.

500. Reflecting Prisms.—The principle of total reflection (494) is applied in many optical instruments. The simplest example is offered by prisms which present a right angle in their principal section.

FIG. 219.



Right angle prism.

Let A B C represent a principal section of a glass prism, and O a ray incident to the surface C B. Since it is normal or perpendicular to this, it enters without being refracted and impinges upon the hypothenuse A B at H. The angle formed by O H with a normal to A B is 45°. The critical angle for glass (494) is 41° 48′; the ray O H, therefore, undergoes total reflection, and passes out of the third face of the prism in the line A T, as indicated. The eye consequently perceives the object O in the position O′.

CHAPTER XXI.

COMPOSITION OF LIGHT.

The prismatic spectrum—Normal dispersion—Abnormal dispersion—Spectrum colors are simple, and of different refrangibility—The rainbow—Newton's theory of composition of white light—Recomposition of white light—The achromatic prism—Heat in prismatic spectrum—Chemical action in prismatic spectrum—Maxima of energies in prismatic spectrum—Light, heat, and chemical action are modes of vibration.

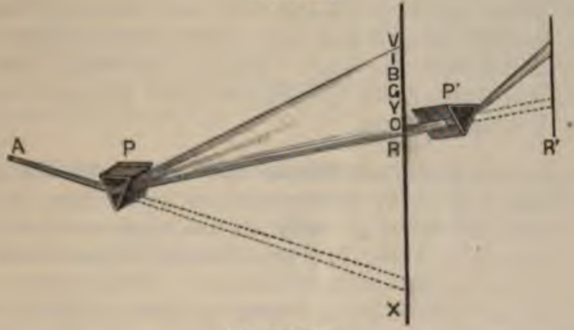
501. The Prismatic Spectrum.—In discussing the action of a prism in the preceding chapter, it is stated that after light has passed through, it is no longer white, but forms a colored elongated image upon the screen. This image is called the *prismatic spectrum*.

For study of the spectrum, the following method and arrangement, Fig. 220, may be adopted. Admit a beam of sunlight through a horizontal narrow slit in the shutter of a dark room at A (a parallel beam from an oxycalcium lantern may be substituted). The line A X then represents its track until it falls upon the screen X. Intervene the prism P with its edge downwards. Revolve it upon its axis until the centre of the colored image formed on the screen is brought as near as possible to X, the original line of light. It is then adjusted to the angle of

minimum deviation for the central part of the spectrum. Submitting this to close inspection, we find:

1st. That it presents an infinite number of tints which gradually merge into each other. For convenience, seven of these

FIG. 220.



The spectrum.

were selected by Newton and spoken of as the *seven primitive colors*, viz., *violet*, *indigo*, *blue*, *green*, *yellow*, *orange*, *red*.

2d. The order in which the colors are arranged is that given; the violet being deviated the most from the original course of light, and the red the least. The deviation of the others is intermediate between these.

502. Normal Dispersion.—The spectrum presents a certain length from the violet to the red; this spreading out of light, and its separation into different colors, is called *dispersion*. Its extent is measured by the angle of separation of any two rays, *e. g.*, red and violet. In Fig. 220 this is represented by R P V. Its ratio to the mean deviation of the two rays is called the *dispersive power*. It is constant for any given medium, while the refracting angle is small. The dispersive power of different substances varies greatly, flint glass having nearly double that of crown glass.

In colored artificial lights, the spectrum differs from that of the sun, the intensity of some colors being diminished. The color which predominates in the flame is the chief in the spectrum. Sometimes a portion of the solar spectrum colors are wanting in flames.

All media which give spectra in which the colors are in the order stated, are said to produce *normal dispersion*.

If the light which has passed through one prism be received upon a second, placed to increase the deviation in the same direction as that produced by the first, the dispersion or increase in the length of the spectrum will be augmented in a similar

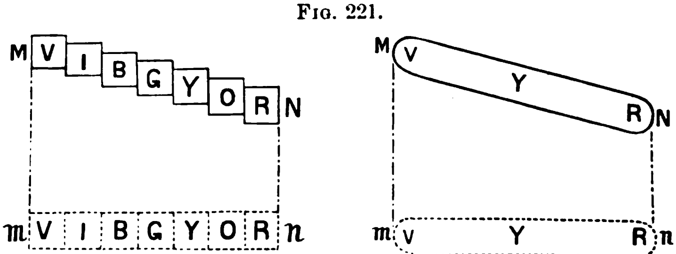
ratio. Thus by using a number of prisms, all acting in the same direction, dispersion may be increased to any required degree.

503. Abnormal Dispersion.—Certain solutions, as indigo and permanganate of potassa, give spectra in which the order of colors is not the same as in normal dispersion. If, for example, a hollow glass prism be filled with an alcoholic solution of fuchsine, the following spectrum results: violet is least deviated; then red, and yellow the most. Kundt has found that all substances with surface color exhibit *abnormal dispersion* when converted into optical prisms.

504. Spectrum Colors are Simple and of Different Refrangibility.—White light having been decomposed by a prism, the question arises: What will occur if each of the seven colors be passed through a second prism? In Fig. 220 the experimental examination of this proposition is delineated In the screen on which the spectrum is formed an opening is made. This is adjusted to allow the red ray to pass through the perforation, it then impinges upon a second prism, P′, placed as the first, edge downwards. The ray is again deviated or refracted, but no further decomposition of light takes place. Changing the position of the prism until the ray is refracted downwards, sideways, or in any other direction, the color remains unaltered. We, therefore, conclude that in decomposition of light by a prism, since each color undergoes no change but that of deviation, the *colors produced in the prismatic spectrum are simple.*

The formation of the prismatic spectrum is, in itself, an evidence that the rays of different colors possess varying degrees of refrangibility, otherwise they would not undergo different

FIG. 221.



Dispersion and deviation.

degrees of deviation. Many additional facts might be cited in demonstration of this; the following will answer our purpose.

If a series of small squares, V I B G Y O R, representing the seven colors of the spectrum, are arranged in order, as at *m n*, and viewed through a prism held with edge parallel to the row, the violet will be displaced the most, the red the least, while the

intermediate colors form a series of steps between the two as at M N.

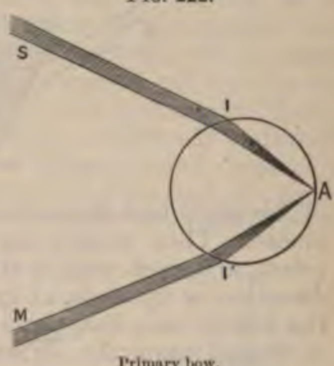
In another experiment contrived by Newton, the light as it emerges from a prism adjusted to give a vertical spectrum, is forced to pass through another, the edge of which is vertical, or at right angles to that of the first. Thus treated, the spectrum changes, it moves to one side, being deviated towards the base of the second prism. The spectrum is no longer vertical, nor horizontal, but takes an inclined or oblique position, the violet being refracted the most, the other colors in their order, and the red the least.

In the figure the manner of change is exhibited, *m n* being the spectrum as formed by the first prism, M N the position when it has passed through both, the violet ray V being refracted the most, the yellow ray Y intermediately, and the red ray R the least.

505. The Rainbow.—This, one of the most interesting of natural phenomena, is the result of decomposition of light by refraction in drops of water. It is only visible when the sun is shining. It, therefore, appears when it emerges from the clouds while it is still raining in the vicinity, or when sunlight falls upon spray produced by waterfalls, fountains, or mists.

Sometimes more than one bow is seen; in all cases a line joining the observer and the sun is the axis of the bow or bows. The track of the rays of light in drops of water in the formation of a primary bow is shown in Fig. 222. The solar ray S I falling on a drop of water at I is refracted to A, there it undergoes total reflection, passes to I′, where it is again refracted, and emerges in the direction I′ M. In this case it is submitted to two refractions, and one reflection; in the secondary bow, it is refracted twice, and reflected twice.

FIG. 222.



Primary bow.

506. Newton's Theory of Composition of White Light.—Having broken up white light into a number of different colored rays by aid of the prism, Newton promulgated his theory of the composition of white light, briefly stated as follows. White light is made up of seven colors of unequal refrangibility, these are called *simple* or *primitive lights*. The variation in their refrangibility is the cause of their separation in traversing a prism.

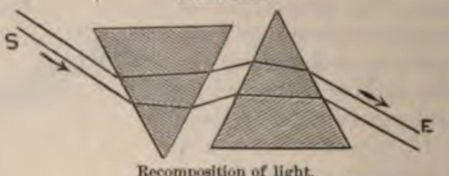
In chemistry the composition of a body is demonstrated in

two ways: 1st, by analysis; 2d, by synthesis. In analysis the constituents of the body are found by separating them from each other, or decomposing the body. By an electric current water is separated into oxygen and hydrogen, and we say we have demonstrated its composition by *analysis*, derived from two Greek words signifying to loosen or separate from one another. Having proved the existence of these two constituents in water, and the proportions in which they are present by analysis, we take the two substances, oxygen and hydrogen, in the proportions found, and by applying a spark determine whether they will unite without any remainder of either body. Actually performing the experiment, we find they do, water being the result. Hence the composition of water having been determined by uniting its constituents in proper portions, we state that we have proved its composition by *synthesis*, also derived from the Greek and signifying a putting together of constituents.

In decomposition of white light by a prism, Newton showed its character by analysis. If, by a process of synthesis, it should again be proved to be compound, its true nature is demonstrated beyond doubt.

507. Recomposition of White Light.—1st. Let a ray of light S be received upon a prism placed edge downwards, as in Fig. 223, and adjusted to produce a spectrum. The usual phenomena

FIG. 223.



Recomposition of light.

of deviation and dispersion will appear upon a screen properly placed. Then receive the rays from the first upon a second prism, arranged close thereto, with edge turned in the opposite direction or upwards, as in Fig. 223. The spectrum formed by the first at once disappears, and in its place a spot of white light is formed upon the screen in the direction E, parallel to the course of the ray incident on the first prism. The second, acting in an opposite sense to the first, has recompounded white light out of the seven prismatic colors. Its compound nature is thus demonstrated by *synthesis*, as well as by *analysis*.

2d. If a convex lens is placed to receive the whole of the spectrum formed by a prism, the different colored rays are superimposed at its focus, and white light produced.

3d. If a concave mirror is arranged to receive all parts of a spectrum, white light is formed at its focus.

4th. If seven plane mirrors are adjusted to receive the seven colors of the spectrum, and their angles arranged to reflect all the colored rays to the same spot, white light is the product.

5th. If powders representing the seven spectrum colors are ground together in a mortar, a grayish-white mixture is obtained. The resultant color is not as perfect as in the preceding, since the colors of powders are not as pure as those of the spectrum.

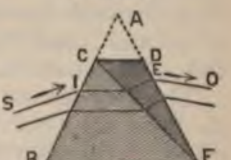
6th. By the device of Newton's disk, another demonstration of the recomposition of white light is obtained. It consists of a circular card, to which rapid rotation may be imparted by suitable mechanism (519). Upon its face the seven spectrum colors are painted, each color occupying a space extending from the centre to the circumference. When rapid rotation is given, the colors disappear, and it seems to be of a uniform light-gray tint. The rotation causes the impressions of the colors to overlap each other on the retina, and their actions are combined, as with the powders, and the effect of white light produced.

7th. By imparting a rapid oscillatory movement to the prism, the colors of its spectrum overlap, and reproduce white light in the central parts of the spectral image.

508. The Achromatic Prism.—In the first experiment showing composition of white light by synthesis, the second prism was similar in all respects to the first, both as regards material and angles. Under these conditions the course of the ray as it emerges from the second is parallel to that of the incident ray on the first. The two taken together have acted like a single block of glass in which the surfaces are parallel, and there is no refraction other than that caused by a medium with parallel faces.

If in place of prisms of the same, those of different materials are employed, in which the indices of refraction and dispersive powers are unlike, we may by a suitable adjustment of angles produce one which will refract a beam of light to a considerable extent, and at the same time give a colorless or achromatic image. Crown and flint glass furnish media having these properties (502).

FIG. 224.



Achromatic prism.

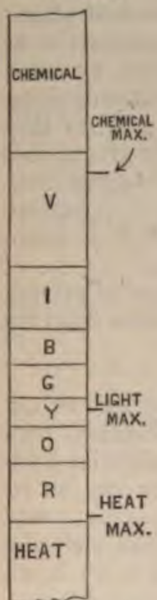
In Fig. 224, let B C F represent the section of a crown-glass prism, and C D F another of the same material. The two acting together would have the effect of one, A B F, and the emergent beam would show refraction and dispersion, and form a spectrum.

Then, suppose the second prism, C D F, is made of flint instead of crown glass. The dispersion of the first is now neutralized, while its refraction is but slightly altered. The emergent ray

E O passes out of the second still refracted, but without dispersion, and gives upon the screen a white spot or image of the sun. To such apparatus the name of *achromatic prism* is given.

509. Heat in Prismatic Spectrum.—Let the central portion, V I B G Y O R, Fig. 225, represent the colors of a solar spectrum formed by a prism. Herschel discovered that if it fell upon blackened paper moistened with water, the surface it covered dried more rapidly than the surrounding parts, and thus an image of the spectrum was produced. Close inspection showed, in addition, that drying began in the lower part of the red, and spread gradually upwards to the violet. At the same time it did not stop in the red, but extended to a considerable distance below.

FIG. 225.



Maxima and minima of energies in prismatic spectrum.

From this it is evident: 1st, that the prismatic spectrum contains heat as well as light; 2d, that the heat spectrum extends far below the visible or light spectrum; and, 3d, that the heat or caloric rays in sunlight are less refrangible than luminous rays.

510. Chemical Action in Prismatic Spectrum.—For blackened paper, substitute a surface coated with chloride, or other compound of silver sensitive to light. Shield it from light, except that part upon which the spectrum falls. The portion occupied by the violet will soon darken, and the sombre hue will gradually extend through the indigo and blue; at the same time it will pass beyond the violet into the region indicated as chemical, Fig. 225.

It is, therefore, evident: 1st. That the prismatic spectrum contains rays capable of producing chemical action, as well as heat and light; 2d. As with heat rays, the *chemical* or *actinic* extend beyond the luminous, in the region of the violet. The distance beyond the violet to which they may be detected is greater than that of the heat rays which extend beyond the red; 3d. Chemical are more refrangible than light rays.

The statements made regarding the position of the stain or darkening by chemical action, must be understood as being the effect of the spectrum upon sensitive silver compounds. Other bodies which undergo change under the action of light are more readily affected in other regions of the spectrum.

511. Maxima of Energies in Prismatic Spectrum.—If fine writing is placed in the spectrum, it can be read with greater facility

and distinctness in the yellow than in any other region. We, therefore, conclude, that for the eye yellow has a greater intensity of action than other colors, and the maximum strength of the light energy of a spectrum is in the yellow.

For the heat energy of the prismatic spectrum there is likewise a position of maximum action. This is in the lower part of the red, or just below it, as is shown by Herschel's experiment, or by direct measurement with a thermo-electric apparatus.

Chemical energy, in like manner, gives a position of maximum intensity, which for silver salts is in the violet. The place of the chemical maximum varies in different compounds. As silver salts are usually employed in photographic operations there is a practical reason why it is given for these substances.

512. Light, Heat, and Chemical Action are Modes of Vibration.—In discussing theories of light, it is obvious that modern physicists believe it is a form of energy, which, originating in vibrations of molecules of a luminous body, is transmitted to us as undulations in the ether. Since the spectrum also presents caloric, and heat energy, which accompany light in its transmission, reflection, refraction, and differ from it chiefly as regards the degree in which they act towards media in these respects, we conclude, that as light originates in vibrations of molecules, so also do heat and chemical energy.

CHAPTER XXII.

CHROMATICS.

Monochromatic light—Color of opaque bodies. Pigments—Iridescence—Color of transparent bodies—Colors of mixed powders—Mixtures of colored lights—Methods of mixing colored lights—Complementary colors—The primary color sensations—Accidental color images—Color blindness—Color and musical pitch.

513. Monochromatic Light.—Flames like sunlight present a combination of colors, as shown on examination with a prism. It occasionally happens that a physical or physiological research requires a simple light of special tint. Where convenient, it may be obtained by a prism, the required color being passed through an opening in a screen, as in (501).

It may also be prepared by the use of monochromatic flames; or by passing white light through colored glass, or through transparent cells filled with certain solutions.

For many purposes a yellow light is necessary. This may be formed by placing a platinum loop armed with carbonate or other compound of sodium in a Bunsen flame, which gives a pure bright yellow light.

A blue light, such as that required in microscope photography to secure coincidence of visual and chemical focus, is obtained by the use of a glass cell with parallel sides filled with a solution of ammonio-sulphate of copper made by adding aqua ammonia to a sulphate of copper solution until the blue precipitate is dissolved.

A nearly pure red may be formed by filling the cell with solution of sulpho-cyanide of iron. A good red is also prepared by staining glass with suboxide of copper. For some purposes a red flame is produced by introducing a platinum wire armed with chloride of strontium into a Bunsen flame.

514. Color of Opaque Bodies. Pigments.—When a spectrum is caused to fall upon variously colored bodies, they only appear of their true tint when placed in the same color. In the other parts they are dark or black. The reason of this is, that they only reflect the color which is of their natural tint, all others being absorbed. The proper material for a screen is, therefore, white, which reflects all colors.

Monochromatic flames or other similar lights produce like results. By the light of the sodium flame, the human countenance takes on a ghastly appearance, only the yellow being reflected, while the red tints are lost or suppressed and appear dark.

The experiment detailed, in which a substance of a given color reflects spectrum light of its own tint succeeds only in white light. Take blue, for example: when white light falls upon a surface which appears blue, though the seven primitive colors are present in the incident light, the blue alone is reflected, and the body appears of the tint of the light it reflects. All the rest are absorbed, and converted into some other form of energy, or they may be transmitted.

The color of pigments and other opaque substances, therefore, arises from the surface decomposition of white light by reflection, sometimes one, but more frequently a greater number of colors are thrown back, and thus the various grades are produced. The character and composition of the reflected light may be determined by examination with a prism.

515. Iridescence.—In this there is a play of various colors of brilliant hues. Green, blue, and red tints rivalling those of the

solar spectrum in splendor, are associated with many natural objects; as, for example, the feathers of numerous species of tropical birds. Often, as in the humming bird, these undergo change with slight alteration in the angle of incidence of the light. The same is also seen in the nacreous or pearly matter lining certain shells, as the earshell or haliotis. These colors are produced by decomposition of light by ruled surfaces.

In other instances, iridescence is developed by thin films, the surfaces of which are in close approximation to each other. An example of this is found in very thin mica, also in soap bubbles, or where oil is diffused over water. Here again light undergoes what might be called a spectrum decomposition or dispersion, like that in ruled surfaces; different colors appearing according as the angle of incidence upon the film is changed.

Iridescence is seen even in the absence of tenuous films of solid or liquid matter, like glass blown exceedingly thin, or a soap bubble expanded to the point of bursting. In cracks or crevices in the interior of glass and other transparent bodies, the most brilliant colors often appear. In many such cases there is no air present. The decomposition of light, therefore, takes place in vacuo, between the walls of the fissure. Newton made a special examination of these phenomena, in connection with the formation of rings between convex and parallel surfaces, which we shall study later on in connection with interference, when it will be seen how strongly all the facts connected with iridescence, and the production of color by polarization, support the undulatory or wave theory of light.

516. Color of Transparent Bodies.—The color of a transparent body is owing to the decomposition of light by absorption during its transmission. Nothing new is added to the light, only certain of the colored components of white light are stopped out. According to their thickness the tints of transparent bodies vary. Solution of chromium chloride appears green in thin layers, and reddish-brown when thick. In this, and similar cases, different colors are removed by selective absorption, the light passed being the sum of the remaining rays of white light.

When glasses of different tints are placed behind each other, the color finally transmitted consists of the combination of those which pass both glasses freely. The final color is not the sum of those of the glasses, but what remains when these are subtracted from white light. The transmitted tint is generally that occupying a space in the spectrum between the others. So, if a yellow and blue are used, green is passed. A combination of red glass made with oxide of copper, and blue or violet glass

of equal depth of tint forms a medium which is almost black or opaque.

When substances are colored by transmitted light, the remaining rays of the spectrum are not always absorbed, sometimes they are reflected from the first surface, or scattered in the interior. An alcoholic solution of chlorophyle appears red by reflected light or when viewed sideways, and green when examined by transmission. These are called dichroic. Very thin gold-leaf exhibits similar properties, being yellow by reflected, and greenish-blue by transmitted light.

517. Colors of Mixed Powders.—In his "Physiological Optics," Helmholtz says: In colored powders each particle is to be regarded as a minute transparent substance, which colors light by selective absorption; since, when we examine thin slices of the substance of which they are formed, they are seen to be transparent. For example, verdigris and cobalt glass. The light reflected from the absolute surface is often nearly white, but the deeper the layer from which reflection takes place the darker is the tint; hence coarse powders of a given material are of a deeper tint than those which are very fine.

Reflection from the surfaces of particles is weakened if they are covered with a fluid having an index of refraction near their own instead of air. A layer of water, and still more one of highly refracting oil, deepens the color.

Since light reflected by powders consists of that from their surfaces, and from different depths, it follows, that in mixtures of powders the final tint, as in superposed glass plates, represents the colors of white light which have not been removed by absorption. A mixture of two pigments is, therefore, darker than would be expected. Vermilion and ultramarine lights, if mixed, produce a purple; but a combination of colored powders of these substances produces a dark gray, with scarcely any purple, since each of these pigments is almost opaque to the light reflected by the other.

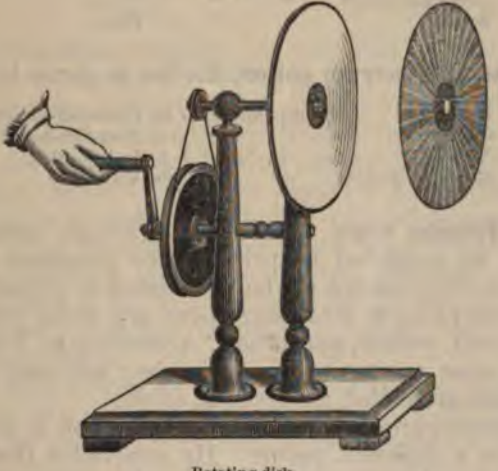
518. Mixtures of Colored Lights.—By this we mean the impressions caused where two kinds of light having different rates of vibration fall upon the same part of the retina at the same time.

In the case of sound vibrations the quality of tone as it affects the ear differs with each change in its formation. A given quality can only be produced by one set of fixed conditions. In the case of colors, on the contrary, each as it appears to our eyes can be formed by a great variety of combinations. Ordinary white light, for example, is composed of all seven colors of the spectrum, but white light, not distinguishable from this by the eye, may be made by taking any elementary

color, from the extreme red to the yellowish-green, and combining it in proper proportion with another color on the opposite side of the green. Though the eye cannot detect the difference, it is discovered at once on analysis with a prism.

519. Methods of Mixing Colored Lights.—Of these a number are given in Deschanel's and other works on physics. Our space only permits a brief description of the more convenient, which are applied to other purposes.

FIG. 226.

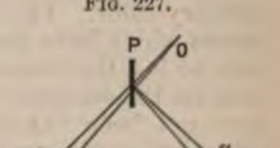


Rotating disk.

The first is known as the method by Newton's rotating disk, Fig. 226. It is provided with a series of paper disks, the surfaces divided into sectors. On one of these the sectors are painted with the seven colors of the spectrum, as described in (507, 6th). On the other disks they are made of such size and colors as the purposes of the experimenter require. The manner of use and mode of action have been described in (507, 6th).

A second method is represented Fig. 227. One colored object, say a blue wafer, is placed at *b*, and another, a green wafer, at *g*. A sheet of clear glass with parallel faces is then held in the position P, so the eye at O sees *b* by transmission of its light through the glass, and *g* by reflection therefrom. The impressions produced by the two colors are thus mingled upon the retina, and the desired result obtained.

FIG. 227.



Complementary colors.

Another method is by forcing two or

more spectra to overlap, the results obtained under these circumstances are the *sums* of the overlapping spectra. When these are projected upon a screen, beautiful combinations of color may be obtained.

520. Complementary Colors are those pairs of tints which give white light when mingled together. According to Deschanel, they are:

Red	complementary	to	Bluish-green.
Orange	"	"	"	Skyblue.
Yellow	"	"	"	Violet-blue.
Greenish-yellow	"	"	"	Violet.
Green	"	"	"	Pink.

In the case of spectrum colors, the list as given by Ganot is:

Red	complementary	to	Greenish-yellow.
Orange	"	"	"	Prussian-blue.
Yellow	"	"	"	Indigo-blue.
Greenish-yellow	"	"	"	Violet.

521. The Primary Color Sensations.—Though seven or more colors may be regarded as primary for purposes of physical investigation, they cannot all be considered as *primary sensations of color*. According to Brewster there are three primary color sensations—red, yellow, and blue. According to Young, Helmholtz, and most modern physicists, they are red, green, and violet. These are called *fundamental colors*.

Recent investigations by Hering, made upon a physiological basis, tend to a different result. He concludes that there are four primary color sensations essentially distinct from each other, viz., red, yellow, green, and blue. These are moreover reducible to two complementary pairs: 1st, red and green; 2d, yellow and blue. Hering also believes that "complementary colors are the result of opposite actions upon the retina, so that there are only two essentially distinct color-affections of that organ, which, with their opposites, produce the two pairs of complementary colors; the one with its opposite produces red and green; the other with its opposite, yellow and blue.

522. Accidental Color Images.—After looking steadily for some time at a bright color, if we turn the line of vision to a white wall, an image of the colored object appears in its complementary color. This is explained upon the hypothesis that the nerves which have been strongly impressed by the bright color have so lost their sensibility, that the balance of action required to cause the sensation of white is lost, and those factors which have not been exhausted are more strongly impressed. Such subjective results are known as *negative accidental images*.

Certain curious effects of contrast may be explained in a similar manner. If white paper is viewed upon a background of strong color, instead of white it often appears of a color complementary to the background. So also beams of sunshine passing into a room through yellowish blinds, produce blue bands when they fall upon a white surface as a tablecloth.

Sometimes when a painfully bright object is regarded intensely, a positive accidental image is produced, which after a little is followed by a negative or complementary image. These may be regarded as extreme instances of persistence of impression.

523. Color-blindness consists in the want of the elementary sensation representing red. Persons thus affected see the solar spectrum as two strong colors connected by a white or gray band near the Fraunhofer line F. One of these colors is probably blue. Its maximum is midway between the lines F and G, and it reaches beyond G to the limit of the visible spectrum. The other color extends into the red part of the spectrum, the maximum being midway between the lines D and E, and vanishes where crimson appears to the normal eye. The scarlet probably appears to the color-blind as a deep dark green; orange and yellow as a brighter shade of the same tint; and bluish-green is nearly white.

From a consideration of these facts Deschanel concludes that "what is called color-blindness should rather be called *dichroic vision*, normal vision being distinctly designated as trichroic. To the dichroic eye any color can be matched by a mixture of yellow and blue, and a match can be made between any three (instead of four) given colors. Objects which have the same color to the trichroic eye have the same to the dichroic eye."

In an article in the "Am. Journal of Sciences and Arts," vol. xiii. page 32, Professor Rood says: "Tait has described an interesting observation, which has perhaps some bearing on Thomas Young's theory of color. While suffering from indisposition, he noticed each time on awakening from a feverish sleep, that the flame of a lamp seen through a ground-glass shade, assumed a deep-red color, the effect lasting about a second. He suggests that the nerve fibrils in the retina also partook of sleep, and on awakening the green and violet nerves resumed their function somewhat later than the red. I have in my own case noticed some instances which seem to point out that after a *nervous shock*, sudden or prolonged, the green nerves (adopting the theory of Young) recover their activity later than the red, and probably later than the violet nerves. The first observation was made twenty years ago, while recovering from

the effects of chloroform, which had been administered by a dentist well known at that time in Munich. Upon regaining consciousness, and raising my eyes to the face of the operator, I was a little surprised at not having previously remarked his unusually ruddy complexion, but the next instant saw that this was due to an optical illusion, for his hair appeared of a bright purplish-red hue. The singular appearance lasted perhaps a couple of seconds, when his hair resumed its natural color, which was *white*. This observation corresponds with that made by Tait.

"I give now an instance where chronic effects of a similar character were noticed by me for a couple of weeks continuously, during convalescence from typhoid fever. In this case white objects appeared of a not very intense orange-yellow hue, the general effect on a landscape being such as is produced by the orange-yellow rays of the setting sun. Here the activity of the green and violet nerves was diminished relatively to that of the red. The auditory nerve was also evidently affected during the same period, but precisely in what way I did not ascertain.

"It is a matter of yearly observation with me, that effects, similar in kind with those first noticed, are produced by prolonged exposure to bright white light out of doors. Under such circumstances white objects no longer appear pure white, but are tinted plainly purplish-red, and rather dull greens assume a gray hue, as though all the green in them had been neutralized, while strong greens are considerably reduced in intensity (saturation). Upon leaving the blinding glare and entering a darkened room, it often for several seconds appears filled with a greenish haze.

"Two of these cases, and probably that of Tait, point out that our apparatus for the reception of waves of light of medium length, is more liable to be over-strained by nervous shocks or by prolonged excitation, than is the case with those designed for the reception of waves of greater or less length. Nervous derangement and prolonged excitation are then causes which may produce temporary green color-blindness."

Since the use of red lights for signalling, either by lanterns or rockets, is almost universal, the substitution of some other device, as variable forms in place of different colors, is very desirable. Accidents which now occur from color-blindness of railway engineers and pilots would be less frequent, and communities could still enjoy the services of men thus affected without taking serious risks.

524. Color and Musical Pitch.—The existence of variation in rate of vibrations as the cause of difference in color, has led to

the attempt to establish an analogy between colors and musical sounds, the seven primary colors of Newton and the seven notes of the gamut (411) being regarded as octaves respectively of light and sound. The resemblance is, however, a forced one, the gradual transitions which mark the spectrum being in strong contrast to the step-like advance from note to note in the musical scale.

Helmholtz, moreover, directs attention to the fact, that if the lavender rays beyond the violet were included, the spectrum has an extent of an octave and a fourth instead of an octave.

CHAPTER XXIII.

LENSES.

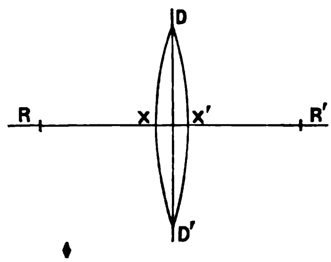
Varieties of lenses—Parts of spherical lenses—Forms of spherical lenses—Action of convex lenses explained—Action of concave lenses explained—Principal and conjugate foci of convex lens—Action of convex lens on convergent rays—Determination of foci of lenses—Optical centre. Secondary axes—Images formed by convex lenses—Images formed by concave lenses—Spherical aberration—The coma—Chromatic aberration—Achromatic lenses—Aberration by curvature of field—Depth of focus—Stops and diaphragms.

525. Varieties of Lenses.—A lens may be defined as a transparent substance, which according to the curvatures of its surfaces causes either *convergence* or *divergence* in the rays of light which traverse it. Though any transparent medium may be used in their construction, they are, in practice, made almost entirely from crown or flint glass, or a combination of both. They are, therefore, spoken of as crown, flint, or compound lenses. The other substances which are occasionally used in making them for special purposes are quartz or rock-crystal, Iceland spar, and rock-salt. A few have been made of diamonds and other gems.

As regards their form, those employed in optics usually have spherical curvatures, but elliptical, parabolic, and cylindrical are also employed.

526. Parts of Spherical Lenses.—In spherical lenses one or both surfaces are parts of the surface of a sphere. Fig. 228

FIG. 228.



Convex lens.

illustrates the section of such a lens made through its centre. The term spherical has no reference to the circumference of the lens by which it is fitted into the brass or other tube, but solely to the curvatures represented in section by D X D′ and D X′ D′.

The line R X′, by which the curve D X′ D′ is described, is its *radius of curvature*, and the point on which the radius revolves is the *centre of curvature;* on the opposite side the centre of curvature for D X D′ is found.

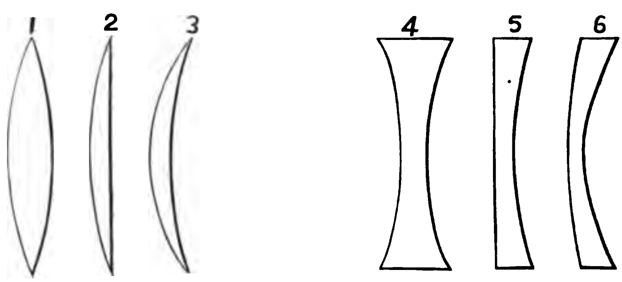
A line connecting the two centres, and piercing the lens at X X′, is the *principal axis* of the lens. Where one surface is plane, the principal axis is the line let fall from the centre of curvature of the spherical face perpendicularly upon the plane face.

The line D D′, drawn from one point of the circumference to that exactly opposite is called the *diameter*. The axis and diameter are perpendicular to each other.

The *aperture* of a lens is the angle between lines connecting the extremities of a diameter with the principal focus.

527. Forms of Spherical Lenses.—There are six forms of spherical lens produced by plane and curved surfaces, as represented in Fig. 229. Of these, Nos. 1, 2, and 3 are *thicker in the axis.*

FIG. 229.



Forms of convex lens.

All such lenses exercise a *convergent* action upon rays of light which pass through them. 4, 5, and 6, on the contrary, are *thinner* at the axis, and produce *divergence.*

In the convergent series, 1 has both surfaces curved outwards; it is, therefore, called a *double convex.* 2 has one surface plane,

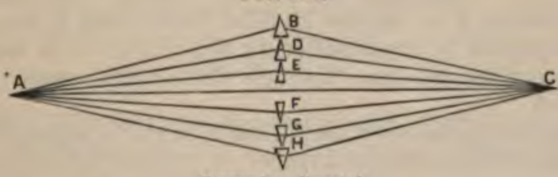
and the other convex; is known as *plano-convex.* 3 has one surface concave, the other convex; and is termed a *converging concavo-convex.* In the divergent series, 4 is a *double concave;* 5, a *plano-concave;* and 6, a *divergent convexo-concave.*

Where one surface of a lens is convex or bulging, and the other concave or hollow, as in Nos. 3 and 6, it is called a *meniscus.* So 3 is a *converging meniscus*, and 6 a *diverging meniscus.* Where the two curvatures are parallel, and little or no true lens action is exerted, the term *simple meniscus* is applied.

528. Action of Convex Lenses Explained.—It was stated in (498) that a ray of light in its passage through a prism is deviated, or deflected towards its base. Upon this and other properties possessed by prisms, all the actions of lenses may be explained.

In the discussion of this subject we quote from Weinhold. "In Fig. 230 let B represent a small prism of glass which re-

FIG. 230.



Convex lens dissected.

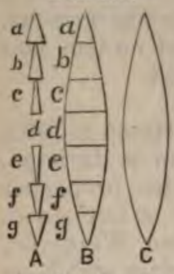
fracts a ray of light proceeding from A in such a manner that it reaches the point C. The prism D, having a smaller refracting angle than B, produces less deviation, and if the refracting angle be suitably adjusted the ray A D may also be refracted towards C; similarly, if the prism E has a still smaller refracting angle, and the latter is properly chosen, the ray A E will meet the other rays also at C. These three prisms have their refracting edges directed upwards; three corresponding prisms, with their refracting edges downwards, viz., the prisms F G H will, if their refracting angles have the required magnitude, refract the rays from A also towards C. Finally, the central ray between the prisms passes from A to C without refraction. It follows that, with a suitable arrangement of prisms, a number of rays which diverge from A may be brought to converge again at a point C.

"It will be easily seen that the series of prisms need not be arranged one vertically above the other. The figure may be supposed to represent a section through a series of prisms arranged in a horizontal line; and, in fact, whatever the arrangement of the series, whether horizontal or vertical, or inclined to either of these directions, the effect will be the same: the

rays from A which impinge upon the prisms will be refracted towards a point C.

"It follows further, since the deviation of a ray does not depend on the distance of the refracting surfaces from one another, but solely upon the angle between them, that a mass of glass of the shape represented in B, Fig. 231, must have precisely the same effect as the combination of separate prisms represented at A in the same figure. The upper and lower portions of B, viz., *a* and *g*, are exactly equal to the prisms *a* and *g* in A; *b* and *f* in B have their refracting surfaces further apart than *b* and *f* in A, but they are in both cases equally inclined to one another, hence they produce the same deviation; *c* and *e* in B are much thicker than *c* and *e* in A, but here also the refracting angles, and consequently the deviation, is the same. The central portion *d* in B has parallel faces, and a ray of light passes through it without suffering deviation; it is the same as if the rays were passing through the empty space *d* in the centre of A."

FIG. 231.



Structure of convex lens.

"A lens of glass, such as C, may thus be considered as a combination of an infinite number of prisms called its *elements*, the refracting angles of any consecutive pair of which differ infinitely little from each other, and such a lens will serve better for collecting rays which emanate from a luminous point, and bringing them to convergence at some other point, than a series of separate prisms whose refracting angles differ considerably."

The plano-convex lens 2, Fig. 229, and the converging meniscus 3, act in the same manner. For all three forms of converging spherical lens the point of crossing of the rays is called the focus. As with a concave mirror, it is a real focus, and will produce an image upon a screen.

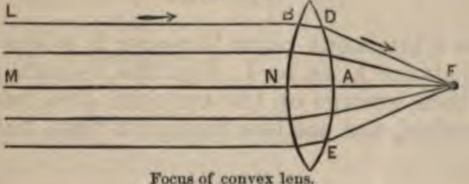
529. Action of Concave Lenses Explained.—In this, as in the preceding case, the principle involved is that of the power of prisms to deflect rays towards their base. Conceive that in Fig. 230, instead of having the bases of the prisms towards the central space, their edges look inwards, it is then evident that the rays from A instead of being converged towards C, would be forced to undergo still greater divergence, and a combination having a divergent action would result. We may, therefore, conclude that a concave lens is made up of an infinite number of prisms, the sections of which have their apices looking towards the centre, or axis of the lens, and their bases towards the circumference. As in the case of convex lenses, the action of the

other forms of concave lenses is explained upon the same principles as for the double concave.

It will be remarked that concave lenses act in a similar manner to convex mirrors, causing the rays which have fallen upon them to diverge. Like their companion mirrors they, therefore, do not have a real focus; but a virtual one may be found by prolonging the course of the emergent rays backwards through the lens.

530. Principal and Conjugate Foci of Convex Lens.—The principal focus of a convex lens is its focus for incident rays L B, which are parallel to its principal axis M N. All such rays will

FIG. 232.



Focus of convex lens.

be converged very nearly to the same focus F upon the principal axis M F, providing the arc D A E does not exceed 10°. The distance F A is the *principal focal distance.*

In all ordinary crown glass lenses where the radii of curvature of the two faces are equal, the principal focus, and the centre of curvature are nearly coincident. When, in place of being parallel the rays falling on a convex lens are divergent, or proceed from a luminous point, the position of the focus and character of the emergent pencil will vary greatly. As with concave mirrors, numerous conditions present themselves.

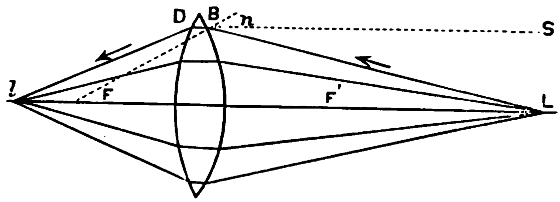
1st. When the luminous point is at the focus of the lens the emergent rays will be parallel, for the conditions are a simple reversal of those in Fig. 232, in which parallel rays are brought to a focus.

2d. Take the same lens and represent its focus for parallel rays by the dotted lines S B B F, Fig. 233. Then, if a luminous point L is placed on its principal axis at a greater distance than the principal focal distance F′, the divergent pencil from L will be brought to a focus at *l*, beyond the principal focus F on the opposite side. In like manner, a luminous point at *l* will be brought to a focus at L. Hence, these are called *conjugate foci*, as with concave mirrors.

3d. When a luminous point *l* is at double the focal distance of the lens, the rays are brought to a focus at an equal distance on the opposite side, and the object and its image are of equal dimensions.

4th. As the luminous point *l* moves nearer to the principal focus F, the focus for the emergent pencil L moves further away; finally, when *l* reaches F, the rays are parallel, and there is no focus, or it is at an infinite distance.

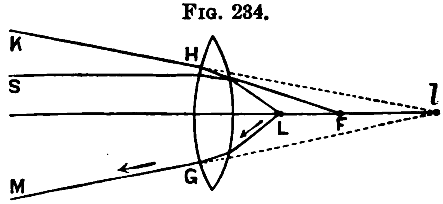
FIG. 283.



Conjugate foci.

5th. When a luminous point is nearer to a lens than its principal focal distance F, as at L, Fig. 284, though the rays H K and G M, which emerge on the opposite side, have undergone convergent action, and are less divergent than before, they still

FIG. 284.



Virtual focus of convex lens.

diverge, and cannot form a true focus. In this, as in a similar condition of affairs in a concave mirror, by prolonging the rays K H and M G along the dotted lines a *virtual focus* is found at *l*.

531. Action of Convex Lens on Convergent Rays.—In Fig. 284, let K H M G represent a convergent pencil of light coming from a long focus lens which would reach a focus at *l*; and H G a double convex lens with F as the principal focus for parallel rays S. When the convergent pencil H *l* M *l* is caught upon the lens, the convergence is increased, and the rays are brought to a focus at L.

By combining together a number of lenses, and increasing the convergence of the pencil of light step by step, the exceedingly short focus and high magnifying power used in microscopes are obtained.

532. Determination of Foci of Lenses.—To determine the principal focus of any convex lens, it must receive the sun's rays

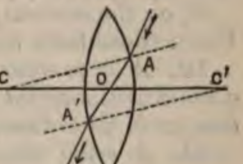
parallel to its axis. The emergent pencil is then projected upon a piece of paper, when the point at which the sun's image is smallest and sharpest is the principal focal distance.

When direct sunlight is not available, the following plan may be followed: Place the lens in front of an object, and project the image upon a screen. Then adjust the relative positions of the screen and lens, until the image and the object are of the same size. Measure the distance from the object to the screen, divide it by four, and the quotient is the focal distance of the lens (530, 3d).

For a double concave lens, cover the face with lampblack, remove this at two small spots, which should be in the same principal section, and at equal distances from the axis. A beam of sunlight is then received on the opposite face, and the screen adjusted, until its position is such that the two spots of light on the screen are twice the distance from each other. This is equal to the focal distance.

533. Optical Centre. Secondary Axes.—The optical centre of every lens is upon its principal axis, and any ray passing through this point does not undergo angular deviation, since the track of the emergent ray is parallel to that of the incident ray.

FIG. 235.



Optical centre.

The position of this point may be found as follows: Let C A and C′ A′ be two parallel radii, drawn respectively from the centres of curvature C and C′ The two plane elements (528) at A A′ on the surface of the lens are then parallel, since they are perpendicular to these lines. The ray A A′, therefore, passes through a medium with parallel faces, and the emergent ray is consequently parallel to the incident ray. The point O at which the ray A A′ cuts the principal axis of the lens is its *optical centre.*

The optical centre of double concave and meniscus lenses can be found by the same method. In plano-concave or convex lenses it is the point where the axis pierces the curved surface.

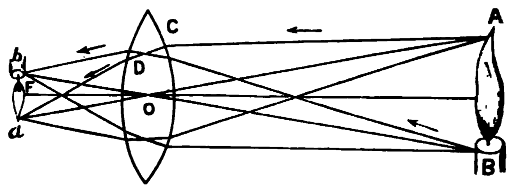
All straight lines which pass through the optical centre of a lens without cutting the centre of curvature are *secondary axes.*

If the secondary axes make small angles with the principal axes, they may be considered as equivalent thereto, as regards all that has been said concerning foci. This is of importance in the explanation of the formation of images by lenses.

534. Images formed by Convex Lenses may be real or virtual, since the image of an object, as in mirrors, is the collection of the foci of the points forming it.

The manner of formation of a real image may be seen from an examination of Fig. 236. A B is the object, placed at a greater distance than the principal focus. A *a* is a secondary axis passing through O the optical centre. A C is a ray which on reaching the lens is refracted first at C and then at D, and cuts the secondary axis at *a*. All other rays from the point A will also meet in *a* as their conjugate focus. A secondary axis

FIG. 236.



Formation of image by convex lens.

drawn from B, and a ray therefrom, will in like manner meet at *b*. All points of A B will thus have their conjugate foci between *a* and *b*, and a real inverted image of A B will be produced at *a b*, which may be projected upon a screen or seen directly by the eye.

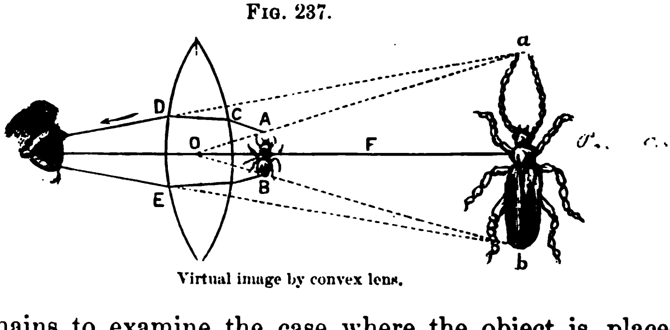
If, on the contrary, *a b* is the object, its image appears at A B. From these facts important consequences follow:

1st. *A large object at a great distance from a convex lens produces a small real inverted image a little beyond the principal focus of the lens, as in an ordinary photographic camera.*

2d. *A small object a very little beyond the principal focus of a convex lens, forms a large real inverted image at a considerable distance beyond the principal focus. Illustrated in the case of the projection lantern.*

3d. *In the first case, the greater the distance the smaller the image. In the second, the nearer the object to the focus the larger the image.*

FIG. 237.



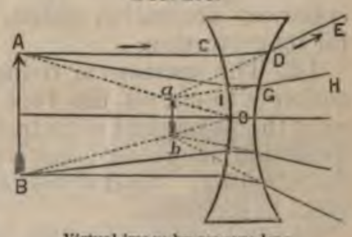
Virtual image by convex lens.

It remains to examine the case where the object is placed between a convex lens and its principal focus, as in the simple

microscope or magnifying glass. Under these circumstances only *virtual images* are formed. In the figure let A B represent the object. Draw a secondary axis O *a* through the point A. The ray A C emerges at D, and if the emergent ray O be prolonged backwards to *a*, it cuts the secondary axis at *a*, which is, therefore, the virtual focus of A. In like manner B finds its virtual focus at *b*, and all points between A and B have foci between *a* and *b*. The eye placed in the position indicated sees the image of A B at *a b*. The image, moreover, is *virtual, erect, and larger than the object.*

535. Images Formed by Concave Lenses.—Like their foci, the images by a concave lens are always virtual. In the figure A B is an object placed in front of a concave lens. A O is then a secondary axis to A. Rays, as A C and A I from A, are twice refracted, and emerging from the lens in the directions D E and G H, diverge from the secondary axis A O. Prolonging the track of the emergent rays D E and G H backwards they cut the secondary axis at *a*, where a virtual image of the point A is seen by the eye placed on the opposite side of the lens. In like manner, images of all the points of A B appear between *a* and *b*. Therefore, *a b* becomes the image of A B. It is *virtual, erect, and smaller than the object.*

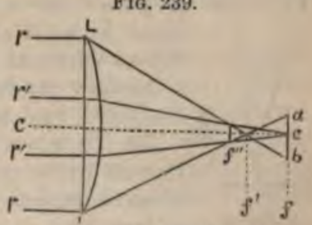
FIG. 238.



Virtual image by concave lens.

536. Spherical Aberration.—In discussing the question of the foci of lenses, it has been assumed thus far, that all rays falling upon the lens meet at the same focal point on the opposite side. This is practically correct while the aperture (526) is not greater than 10°. When it exceeds this, as in Fig. 239, the rays r' r', which emerge from the central parts, L, have a longer focal distance, c, than those, r r, which emerge from the parts near the edge, as at f' in the figure. To this phenomenon the name of *spherical aberration by refraction* is given, and the intersections of the refracted rays are called *caustics by refraction.*

FIG. 239.



Spherical aberration.

By Fig. 239, it is also evident that spherical aberration may be examined in two ways: 1st. As regards the distance from c, the focus of the central rays to f', that of the marginal. This

is called *longitudinal spherical aberration.* 2d. The rays r' r' come to their focus at c, while r r reach theirs at f', and then diverging form an aureola around the image produced by the central portions of the lens. The diameter of this is represented by a b. To it the name of *lateral spherical aberration* is given. The position of least aberration is between f' and f.

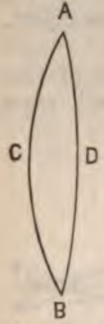
Longitudinal aberration increases or diminishes as the square of the diameter of the aperture, and inversely as its focal length. Lateral is proportional *to the cube* of the aperture, and inversely proportional to the square of the focal length. Or, double the diameter, and the longitudinal is increased four times, and the lateral eight times. The diameter remaining the same, and the focal length being doubled, the longitudinal is reduced to one-half, and the lateral to one-fourth.

It being impossible to obtain clear or sharp definition while spherical aberration exists, various methods are resorted to for its correction.

1st. The aperture is reduced by means of *stops* (542). Their action is to cut off the rays from the circumference, and allow only the passage of a central pencil. Thus greater sharpness of definition is gained, but at serious cost in the brightness of illumination. At the best this plan is only partial, never complete in its action.

2d. By constructing the lens with faces of different radii of curvature—A C B, A D B. The extent and character of this variation depends upon the distance of the object. If the radiating point is at infinity, the most convex surface should be turned towards it, and for crown glass the radii of curvature should be as 1 : 6.

FIG. 240.



Crossed lens.

As the radiating point approaches the lens, the surface towards it should become less and less convex as regards the other face; *e. g.*, the radii should be 2 : 5 — 3 : 4 — 4 : 3 —until when it reaches the principal focus it should be 6 : 1, or the reverse of what it was when at infinity.

Lenses made on this principle are called *lenses of best form*, and also *crossed lenses.*

3d. In place of using a single one of short focus, two or three convex lenses of longer focus are placed close together. Thus a combination of the same short focus, but with considerably less spherical aberration, is obtained.

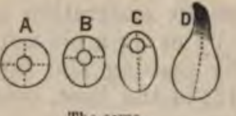
4th. By combining a concave lens with the convex. The material of the second may be similar to that of the first or unlike. Usually it is different.

The manner in which this acts is easily understood when we reflect, that in the concave or diverging lens the thickness is

greatest at the circumference, hence the aberration is in an opposite direction to that of the convex, and corrects it. It is, therefore, only necessary to secure a proper relation of radii of curvatures in both, when a converging combination almost entirely free from spherical aberration is obtained. Lenses of this description are called *aplanatic.*

537. The Coma.—Spherical aberration has thus far been considered only as applied to rays parallel to the principal axis. It remains to speak of the consequences arising when rays fall upon a lens obliquely to its axis. In Fig. 241, suppose

FIG. 241.



The coma.

the aberration for parallel rays is represented by A, the space between the interior and exterior circles being the aureola of aberration. B and C then represent the changes that take place as the rays become more and more oblique to the axis, until finally the appearance at D is produced. To this the term *coma* is applied.

A lens which is aplanatic for rays parallel to its axis, is not so for those oblique thereto. The correction for this condition is attained in part by the use of properly placed diaphragms.

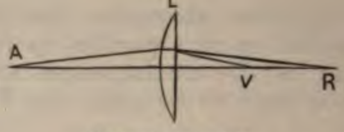
538. Chromatic Aberration.—All simple lenses give images the margins of which show coloration which does not belong to the original. This sequent of lens action is called *chromatic aberration.*

In describing the action of lenses (528) it was shown that the principle involved was that of refraction, as with prisms. Since, a lens is in fact a combination of an infinite number of prisms, it follows that as a prism not only refracts light, but also decomposes and disperses it into different colored rays, a lens must have the same effect, and hence the coloration of the margins of the images it produces.

In Fig. 242 this action is represented, A being the luminous point, L the lens. As the violet rays are the more refrangible, they come to a focus at V, while the red are prolonged to R. The maximum for light is in the yellow (511), while that for chemical rays is in the violet region. Setting aside the annoyance arising to the eye from marginal coloration, it

therefore follows, in photographic operations, that when an image is sharply focussed on the ground glass, the photographic picture is badly out of focus. Hence we perceive there are two foci for a simple lens, viz., the *visual focus* and the *chemical focus.*

FIG. 242.



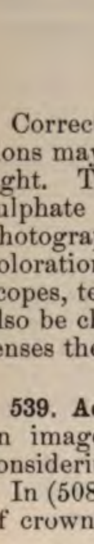
Chromatic aberration.

Correction for chromatic aberration in photographic operations may be obtained by using a blue or violet monochromatic light. The method by passing the light through ammonio-sulphate of copper (513) is the best, especially for microscopic photography. This does not answer for removal of marginal coloration in optical contrivances used by the eye, as microscopes, telescopes, etc., as the natural colors of the object would also be changed or interfered with. For such instruments the lenses themselves are corrected as follows.

539. Achromatic Lenses are so called because they furnish an image free from the marginal coloration we have been considering.

In (508) the achromatic prism is described. It is composed of crown and flint glasses, the dispersive power of which is so different, that by a combination of the two dispersion is corrected, while considerable refractive power remains. It is upon this principle that the achromatic lens first made by Dolland depends for its mode of action.

FIG. 243.



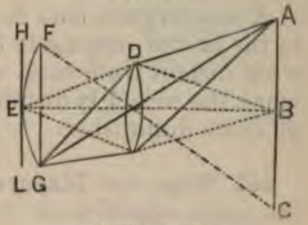
Achromatic lenses.

In Fig. 243, A represents a concave or diverging meniscus of flint glass, and B a convex or converging lens of crown glass. These have one face in common, by which they are usually cemented together. Their curvatures are, moreover, so adjusted that they are aplanatic, and not only chromatic but also spherical aberration (536) is corrected.

While achromatic lenses give an admirable optical image, they often fail to give good photographs from a want of coincidence in the visual and chemical foci. This can be corrected either by making a suitable change in the position of the plate, which is determined by trial, or by passing the light through an ammonio-sulphate of copper solution (538).

540. Aberration by Curvature of the Field.—Let A B C represent a plane at a distance from the convex lens D. The rays from the point B will come to a focus at E, while those from A and C will reach their foci at F and G respectively. The points E F G, being nearly equidistant from the optical centre of the lens, the field will consequently be curved, and an image cannot be formed on the plane H L, in which both the central and marginal portions are sharply defined. To this aberration the name of curvature of the field is given. In the eye the image is received upon the interior of a sphere which offers a field of the curvature in question.

Fig. 244.



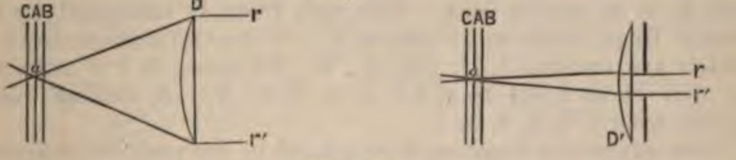
Convex image.

The correction of this in photographic lenses is accomplished by a proper relation of the position of the diaphragm to the radii of curvature of the lenses forming the combination.

541. Depth of Focus is the property of giving well-defined images in planes of unequal distances from the optical centre of the lens. This may be experimentally illustrated as follows. Take an opera glass and focus it for objects at a distance. Then direct the glass to those nearer, they will appear equally well defined, yet the foci for the near and distant are not the same. Again direct the glass to a distant object, it will then be found that the eye-piece may be moved forwards and backwards through a small distance without injury to sharpness of definition. This distance represents the depth of focus of the lenses.

This property varies with the aperture, as in Fig. 245. Let D represent a lens in use with its full aperture exposed, the parallel

Fig. 245.



Depth of focus.

rays r r' come to a sharp focus at a in the plane A. Movement of the ground glass receiving the image towards the planes C or B, instantly injures the definition.

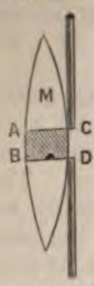
Suppose that a stop is placed in front of the lens and its diameter reduced as at D′. The parallel rays r r' passing

through this portion, since they converge at a much smaller angle than in the preceding instance, appear to give equally sharp images, whether the screen is at the distance A, or at B or C.

A convergent lens can, therefore (in apparent contradiction to the law of conjugate foci), give sharp images in planes somewhat distant from each other. This, however, only takes place when the object is distant from it; as it approaches, the depth of focus diminishes.

542. Stops and Diaphragms.—Formerly these terms possessed the same significance in physics, but great advances in construction of photographic lenses have led to a special application of each term. The apparatus is the same, consisting of a disk of metal equal in diameter to the lens, and having a central aperture which varies in each, so a series with different openings is formed which can be used either as stops or diaphragms, according to their position.

FIG. 246.



Stops and diaphragms.

When used as a *stop*, it is placed close to the lens M as in C D, Fig. 246. It then cuts down the aperture to the diameter of the opening of the stop, and only the central portions, A B C D, are in use, and represent the full size of the pencil of rays that can pass it.

When, on the contrary, it is placed at a proper distance it becomes a diaphragm. The full aperture is employed, and only those rays from different parts of the lens which it is necessary to cut off are interfered with. In all ordinary optical instruments their position has been fixed by the maker, and care should be taken not to change or disturb them.

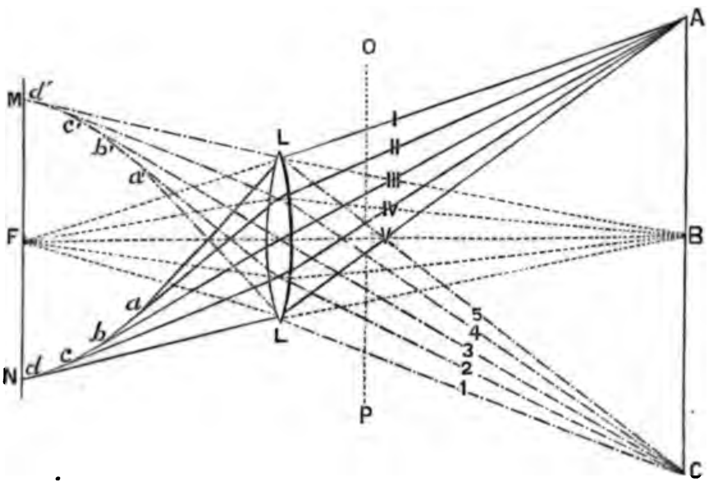
In explanation of the action of a diaphragm, let us consider the conditions Fig. 247. A B C represent three distant points, and L L a convex lens. The rays from B indicated by the dotted lines, come to a focus at F. Not so with those from A, which are marked I, II, III, IV, V. Of these, A I is refracted to *a*, A II to *b*, III to *c*, IV to *d*, V to N. A similar result occurs with C 1, 2, 3, 4, 5.

Now suppose a diaphragm be placed in the position indicated by O P. The conditions in Fig. 248 then arise. Only the rays 4 and IV, 5 and V, from A and C, which have their focus near the same plane as F, can reach the ground glass screen. Others which injure definition have been thrown out, and the image gains in sharpness thereby.

It is, in addition, evident that the smaller the opening of the diaphragm the cleaner cut the image. To this there is a limit,

as after a certain size is reached any further diminution causes phenomena of diffraction to appear, which injure the definition

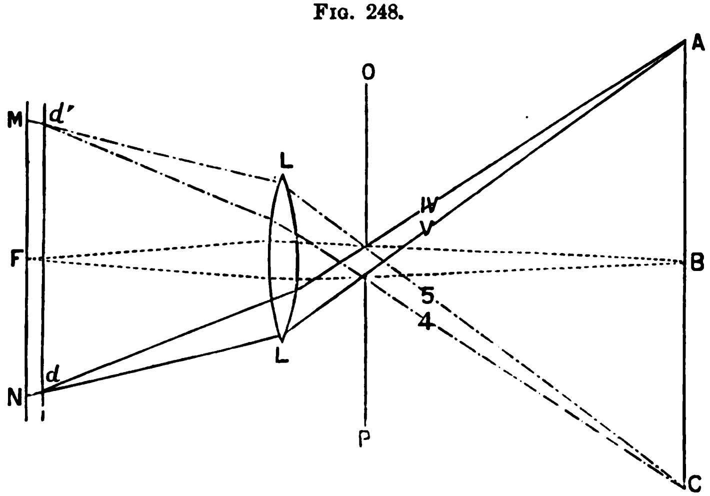
FIG. 247.



Spherical aberration.

of bright objects. A star, for example, in place of appearing as a point, seems surrounded by rings.

FIG. 248.



Action of diaphragm.

In place of diaphragms formed in the manner described, a very ingenious arrangement called the *iris diaphragm* is attached

to microscopes and other instruments. It consists of a series of radiating plates which surround a central opening. By revolving a ring on the exterior, their position and the size of the central opening are altered. The change of aperture imitates that seen in the iris of the eye.

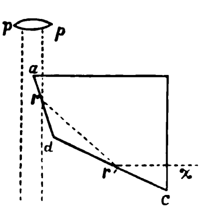
CHAPTER XXIV.

FORMATION OF IMAGES BY REFRACTION.

The camera lucida—The camera obscura—The magic lantern—The solar microscope—The oxyhydrogen lantern—Photo-electric lantern—The megascope.

543. The Camera Lucida is an instrument frequently used in sketching objects viewed through the microscope. In that invented by Wollaston, in 1804, the principal section is as represented, Fig. 249. It is a four-sided glass prism, acting by total reflection. The angles are, two of 67° 30′, one of 90°, and one of 135°. A ray entering normally in the direction $x\ r'$, is totally reflected from the face $d\ c$, in the direction $r'\ r$, impinging upon the face $d\ a$, since the angle formed is again greater than the critical angle, it undergoes a second total reflection, and emerges in the line $r\ a$. The eye placed at $p\ p$ perceives the object in the direction indicated by the dotted lines, and if the adjustment is such that the edge of the prism only occupies half of the field of vision, it is projected upon a surface of white paper placed at a distance of about ten inches from the eye. If the point of a pencil is placed thereon it is seen with equal distinctness, and the image may be easily traced with it. In some cases a lens is added, as at $p\ p$.

FIG. 249.



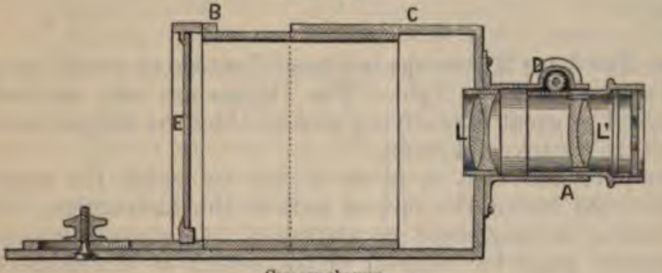
Camera lucida.

544. The Camera Obscura was the invention of Porto, a Neapolitan physician. In its first form it was a long double rectangular box. One section, B, was smaller than the other, C, enabling it to slide therein, as in an ordinary telescope, making the box of different lengths. At one end, L, a minute opening was made. The opposite end was formed of a flat sheet of ground glass, E. Directing this towards an illuminated landscape, the

rays therefrom formed an inverted image on the ground glass the size and brightness of which were varied by sliding this section of the box nearer to or further from the aperture.

In place of using a minute aperture for the entrance of the rays, Porta soon found that by substituting a convex lens L a

FIG. 250.



Camera obscura.

much brighter image was produced, the definition of which was easily perfected by a slight forward or backward movement of the ground glass.

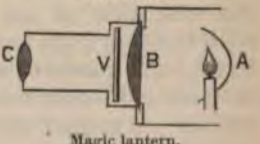
In this form, with various improvements in the character of the lenses L L′, and means of focussing D A, the camera obscura has now become the well-known photographic camera.

The term camera obscura, as its name indicates, is also applied to rooms of considerable dimensions, and generally in the form of a tent. At the apex of this there is a lens and prism so combined, that the latter reflects the image produced by the former in a downward direction upon a table placed in the centre of the room, as the screen of the camera. Visitors looking at the table, obtain a panoramic view of all that passes across the field of view outside the building.

545. The Magic Lantern is an instrument the operation of which is exactly the reverse of the camera, for while the latter produces a diminished image of the object, the lantern forms an enlarged one.

The essential parts of the apparatus are a tin box, in which a lamp of some form is the source of light. By means of a parabolic mirror, A, as much as possible of the light is passed through the convex lens B, and concentrated upon V, the object to be reproduced. At C there is a double convex lens, the position of which from V is a little more than its own focal distance. The action of the

FIG. 251.



Magic lantern.

apparatus is to form a real and magnified image of the object upon a screen.

The so-called dissolving views are produced by using two similar lanterns, in which different pictures, or slides, have been placed, and directing the images upon the same parts of the screen. As the light is gradually shut off from one and turned on the other, the former merges gradually or dissolves with the latter.

546. The Solar Microscope is a magic lantern in which the sun is used as the source of light. The objects are very minute, and subjected to great magnifying power—like the magic lantern, it is used in a darkened room.

The parts are: 1st. A plane mirror by which the solar rays are directed along the optical axis of the instrument. 2d. A condensing arrangement consisting of two convex lenses. 3d. A suitable stage for support of the object at the focus of the condensing system. 4th. The projecting apparatus generally formed of one or more achromatic lenses, the whole having a very short focus, and consequent high magnifying power.

The intense heat at the focus is apt to injure objects submitted to its action; to avoid this, the solar rays are passed through a saturated solution of alum, enclosed in a glass cell, with flat parallel walls.

547. The Oxyhydrogen Lantern.—The *oxycalcium light* resulting from projecting the flame of mixed oxygen and hydrogen gases upon a cylinder or pencil of calcium oxide is generally employed. It is fixed in its position in the optical axis of the apparatus, and thrown into operation with comparative facility when cylinders containing the compressed gases are available. It has sufficient intrinsic brilliancy for the majority of experiments. The difficulties in the way of its use are, however, serious, and it is very desirable they should be lessened. They arise chiefly from the volatility of the calcium oxide at the intensely high temperature employed. The volatilized material depositing on the condensing lenses prevents the passage of luminous rays, and the cavity formed in the cylinder of lime at the spot where the flame impinges soon diminishes the brilliancy of the light; this necessitates a change in position of the lime cylinder to present a new surface to the flame, and this in its turn implies a distraction of the attention of the experimenter, which interferes seriously with the thorough management of his subject. Though attempts have been made to avoid this difficulty by clockwork, or other mechanical contrivances, they are still unsatisfactory in their action. Another serious objection is the necessity of placing

the cylinders in a closed vessel when not in use to protect them from action of the air.

The *oxymagnesium light* is similar to the preceding, differing only in the substitution of a cylinder or pencil of magnesium oxide for calcium oxide, and the light emitted is of equal brilliancy. Following the instructions given for preparation of these cylinders, I have taken the greatest pains to procure samples of magnesium oxide of the utmost purity. I have also tried various other methods, among which the combustion of the metal in oxygen may be mentioned, but failure has thus far attended all efforts to make pencils or cylinders able to withstand the intense heat of the flame of mixed oxygen and hydrogen gases without undergoing volatilization. The pencils obtained were fully equal in this respect to those of calcium oxide; but I did not find any superiority that repaid me for my trouble.

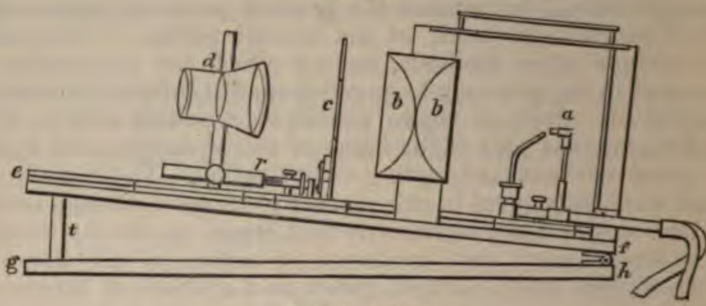
The *oxyzirconium light* produced by action of the flame of mixed oxygen and hydrogen gases on a cylinder of zirconium oxide meets every requirement. It has intrinsic and invariable brilliancy, a fixity of position in the optical axis of the apparatus, and does not volatilize under the heat employed. The condensing lenses remain free from deposit, and after the light is once adjusted the experimenter can carry on his demonstrations without any distraction of attention that attends the use of other lights. All that is necessary is, according to the size of the reservoirs of compressed gas, to open the cocks a little as pressure diminishes. There is also no need to remove the zirconium oxide pencil from its position, as with calcium oxide; it may, on the contrary, remain *in situ* for any length of time, and is always ready for use.

In lanterns as ordinarily constructed for projection of photographic or other images on a screen, the support or stage on which the photographic slide is placed is close to, and at an invariable distance from, the condensing lens. While the objects projected are nearly equal in size to the diameter of the condenser, this is the only adjustment that can be made to illuminate their whole surface; but, when the diameter of the field occupied by them is only one-half or one-quarter that of the condensing lens, the brilliancy of result obtained may be greatly increased by removing the supporting stage or object-carrier to a greater distance from the condenser, allowing a convergent beam of light to fall on the object. To accomplish this I have constructed the following form of lantern:

In Fig. 252, *a* is a zirconia light, mounted on an adjustable base (see "American Journal of Science and Arts," Sept. 1877, page 208), which may be used with a condensing lens of very short focus, since the zirconia is not burrowed into cavities where the oxyhydrogen flame impinges, which happens with lime

cylinders, and causes the flame to be reflected upon the condensing lens, thereby destroying it. In the jet employed, the gases are mixed just before ignition. *b b* is a short focus condensing combination. *c* the stage or support carrying the pho-

FIG. 252.



Projection lantern.

tographic or other design to be projected. *d* the projection lens formed of three sets of lenses, and giving a perfectly flat rectilinear field. *a c d* are mounted on a base board, *e f*, to the end of which the lantern box *a b* is attached, freely open above and below to permit perfect ventilation. The base carries lateral grooves in which *a c d* slide, allowing them to be placed at varying distances from *b*, and fixed by suitable binding screws. *c* and *d* are also connected by a rod *r* carrying an adjustment screw at *r*, by which change of distance between *d* and *c*, required in giving the correct focus, is obtained. The base *e f* is attached to a second or under base *g h* by a hinge at *h*, which allows the end *e* of the movable base *e f* to be raised to any required angle, at which it may be maintained by a block at *t*. So convenient and compact is this lantern that it can readily be stowed away in a small trunk.

When a series of objects of different sizes is projected, as with microscopic photographs taken under the same adjustments, it is a great gain in the projection of smaller objects if the circle of light used for illumination is reduced; and at the same time increased in brilliancy. This is accomplished as rapidly as can be desired by removing *d c* together, along the slide of the base *e f* to a sufficient distance from the face of the condenser *b* to allow the convergent rays from the latter just to cover a circle which will include the object. The greater intensity of illumination thus obtained renders the definition of fine markings or other peculiarities on small objects as clearly visible at considerable distances as are coarser ones on those of a larger size under a weaker light.

For projection of the spectrum a slit is placed in front of the condensing lens. This is brought to a focus on the screen by the projecting lens. One or more prisms, according to the character of the experiment, are then placed on a platform in front of, or close to the outermost lens of the projecting combination, when a fine spectrum will appear in the proper position. To obtain the best results, the prisms should be adjusted for minimum deviation.

The form of this lantern also permits its use as a projecting microscope. An alum cell (546) is placed between the condenser *b b* and the stage *c*. A microscope objective combination is substituted at *d*. Thus arranged, I have shown the circulation in the web of a frog's foot, so that blood-corpuscles could be seen moving in single file through the smallest capillaries, each perfectly distinct, and about an inch in length.

For projection experiments in polarization, the outer element *b* of the condenser is removed, and a nearly parallel beam obtained. This is received upon a reflecting polarizer of fifteen or twenty plates. The polarized beam is thus cast downwards, when it is received on a surface of polished silver, and sent through the axis of the projecting lens, which must be placed lower for the purpose, and armed with a Nicol or a double image prism, as an analyzer. By this arrangement I have exhibited on the screen all the usual experiments in polarization, including the colored rings and black cross of calc-spar, and demonstrated the method of determining the strength of sugar solutions. In the latter case the amount of rotation was shown by taking a portion of the transmitted beam and by suitable mirrors causing it to act as an index. Movements of the spot of light through an arc of forty-five degrees were readily obtained by solutions of sufficient strength.

548. Photo-electric Lantern.—Of all artificial lights the electric arc is the most brilliant and its use in lanterns has often been attempted. The difficulty, however, is, that no regulator has yet been contrived which can furnish a perfectly steady light. Where the dynamo-electric current is employed, the variation therein, produced by slipping of bands, and other irregular actions of the mechanism, cause a distressing effect upon the eyes of those who are watching the projected images. By the use of the new condensing batteries it is possible that this trouble may be overcome. Until this is done, the electric light, in spite of its intrinsic brilliancy, cannot equal the zirconia light in the projecting lantern.

549. The Megascope is employed for the projection of images of coins and other opaque objects. It requires the use of lenses

of considerable diameter, and a most brilliant illumination of the object. The magnifying power obtained is not very great, but is sufficient to enable the experimenter to exhibit such phenomena as the pulsation of the heart to a large audience.

CHAPTER XXV.

THE EYE AND VISION.

Parts of the eye—The mechanical mechanism—The optical mechanism—The sclerotic and cornea—Crystalline lens—The humors of the eye—The iris—The second tunic or choroid—The third tunic or retina—Terms applied to optical mechanism—Accommodation—Normal action of optical mechanism—Abnormal action of optical mechanism—Spectacles—Binocular vision—The stereoscope—Size and distance of objects.

550. **Parts of the Eye.**—*As the ear is the organ of time, so the eye is the organ of space.* Its function is to form images of external objects upon the retina, and bring them under the cognizance of the brain or organ of the mind. The eye is generally described as consisting of: 1st, the mechanical mechanism by which the principal axis of the organ is directed towards the object to be viewed; 2d, the optical, by which the image is formed upon a screen, and brought to a sharp focus; 3d, the nervous, by which the image is perceived by the mind; 4th, certain appendages as the eyelids, eyelashes, lachrymal glands, ducts, and mucous membrane or conjunctiva. Of these the 1st and 2d especially command our attention. The 3d and 4th are more purely physiological in their character.

551. **The Mechanical Mechanism** consists of muscles and tendons so attached to the eyeball and the cavity or orbit in which it is placed, as to move the principal axis of the organ in different directions. Four of these pass straight forwards from the apex of the orbit to the ball; they direct the axis upwards, downwards, to the right or left. By means of two others, called the oblique, the ball is rotated upon its axis. In all of these except one the action is direct. In the superior oblique the tendon is long, and passes through a tendinous ring in the inner side of the orbital cavity, giving an example of the application of the pulley to the change in direction of a line of force. An exces-

sive contraction of any one of these muscles constitutes the condition called squinting or strabismus.

552. The Optical Mechanism may be likened to a camera obscura, as regards its parts and manner of action. The box is represented by the sclerotic and cornea; the lenses by the crystalline lens, aqueous and vitreous humors; the diaphragm is the iris, and the screen is formed by the retina, or nervous mechanism, and the black pigment.

553. The Sclerotic and Cornea taken together form a nearly spherical box about an inch in diameter. They constitute the exterior coat or first tunic of the eye, as at *a* and *d* in the outline of the eyeball, Fig. 253. All the wall, excepting a small an-

FIG. 253.

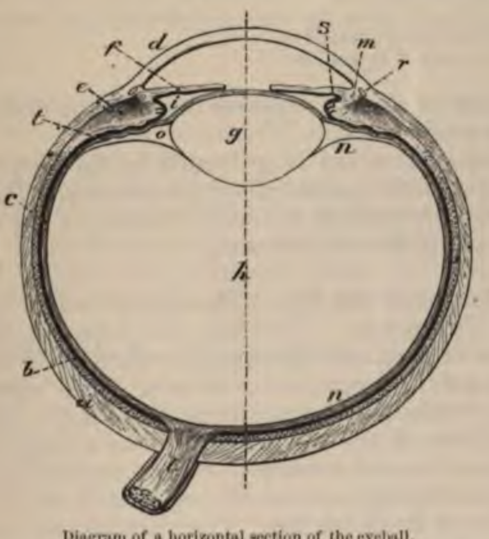


Diagram of a horizontal section of the eyeball.

a. Sclerotic coat.	*i.* Posterior chamber.
b. Choroid and black pigment.	*l.* Optic nerve.
c. Retina.	*m.* Ciliary ligament.
d. Cornea.	*n.* Hyaloid membrane.
e. Ciliary muscle.	*o.* Canal of Petit.
f. Iris.	*r.* Sinus circularis.
g. Crystalline lens.	*s.* Ciliary process.
h. Vitreous humor.	*t.* Suspensory ligament.

terior portion, is composed of the sclerotic, which is a dense, tough, opaque, fibrous tissue, and appears in what is known as the white of the eye. The anterior portion is the cornea, *d*; it may be regarded as the continuation of the sclerotic, since it is

made up of the same tissue. It differs, however, in that it is transparent, and its curvature also is greater. As its surfaces are parallel to each other, it is a simple meniscus, having of itself but little lens action. Its real function is to form the anterior surface of the aqueous humor, and give to that fluid a true lenticular form and function.

554. **Crystalline Lens** is a double convex lens, *g*, Fig. 253, of unequal curvatures, the anterior surface being less convex than the posterior. It is one-third of an inch in diameter, one-sixth thick, and enclosed in a membrane, called its capsule. It has sufficient consistency to retain its figure when removed from its position, though it yields readily to pressure. It is built of layers the density of which gradually increases towards the centre, as shown in the following determinations of their refractive indices, by Brewster:

Exterior layers of crystalline	1.3767
Central layers of crystalline	1.3990

By this increase in refractive power towards the centre spherical aberration is diminished.

The position of the lens is governed by the suspensory ligament *t*, ciliary muscle *e*, and ciliary processes *s*. The action of these is largely involved in the *accommodation* of the focus of the eye to objects at different distances.

555. **The Humors of the Eye.**—These are two in number, the *aqueous* and the *vitreous*. The first lies between the posterior surface of the cornea and the anterior surface of the lens. It is, therefore, a fluid concavo-convex lens. The second *h*, occupies the space between the posterior face of the lens and the retina at the back of the ball; it also forms a concavo-convex.

Both of these have a density less than that of the lens. As regards its physical appearance, the aqueous is, as its name indicates, quite fluid in character. The vitreous, on the contrary, has a consistency similar to that of the white of an egg. It is enclosed in a membrane called the *hyaloid*. In connection with the crystalline lens which lies between them, these keep the hollow sphere or cavity of the sclerotic and cornea distended, and maintain its spherical form.

The refractive power of the media composing the eye as compared with water, is as follows, according to the determinations of Brewster:

Water	1.3358
Aqueous humor	1.3366
Vitreous humor	1.3394
Crystalline average	1.3839

556. The Iris is in the aqueous humor, and close to the crystalline lens, *g*. It is represented at *f*, Fig. 253. It forms the colored (blue, gray, or brown) portion of the eye, which we observe when we look into that organ. In the centre there is an opening, called the pupil. In the normal state this always appears black, because through it we see the dark coating, or black pigment, which with the retina forms the screen.

The iris divides the aqueous humor into the anterior and posterior chambers, *i*. It is not perfectly flat, its central region bulging slightly forwards, as in the figure. It is highly vascular, and composed of radiating fibres which pass from its circumference to the circular elastic band forming the margin of the pupil, and acts as its sphincter. By contraction of this the diameter of pupil is diminished, by relaxation it is increased. It thus regulates the size of the pencil of light entering the eye. Being close to the lens, it acts as a stop thereto, and by excluding rays from its margin aids in correcting spherical aberration.

557. The Second Tunic or Choroid.—If we make a section of the eyeball from before backwards, through its centre, Fig. 253, we find that nearly all that portion of the wall which lies behind the iris and includes the vitreous humor, is composed of three layers or coats. The exterior is the sclerotic *a*, which we have examined. Immediately within this, and in close contact, is a second coat, *b*, made up of bloodvessels, and cells filled with black pigment which give to it a dark, velvety look. This is the choroid.

In its anterior portion it separates from the sclerotic near where the latter becomes cornea, and turning inwards and being supplied with muscle cells forms the iris, *f*, described in the last article. As it leaves the sclerotic, it separates into two laminæ, the anterior forming the iris, and the posterior a series of loops which surround the lens. These are known as the ciliary processes, *s*; they are about seventy in number. Beneath the ring of these, and in contact with the sclerotic, there is a band of radiating muscular fibres called the ciliary muscle, *e*, which has a most important relation to the accommodation of the eye for objects at different distances.

558. The Third Tunic or Retina, is the expansion of the optic nerve, Fig. 253, *c*. By some it is regarded as the screen of the optical mechanism, as well as the organ by which the image is perceived. By others the black pigment of the choroid coat is considered to be the screen, while the retina perceives the image produced thereon. Those who believe the retina is both screen and organ of perception, allow that the duty of the black pig-

ment is merely to extinguish the light after it has served its purpose. A very interesting view of the function of the black pigment will be found in Prof. J. W. Draper's "Human Physiology," page 390. He directs attention to several points, which show that its true function is to act as the screen, while the retina perceives the image formed thereon. One of the most significant of the facts brought forward, is, that the sensitive columns of the retina are directed backwards toward the pigment, and not forwards toward the lens, as would be the case if they formed the true screen.

There are four layers of the retina, according to Müller. These are arranged radially, from within outwards, in the following order: 1st, fibres of optic nerve; 2d, vesicular layer; 3d, granular layer; 4th, Jacob's layer of cones and rods.

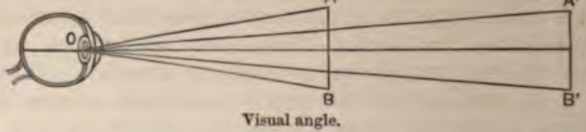
559. Terms Applied to Optical Mechanism.—1st. *Optic centre of lens*, which may be determined according to method given in (533).

2d. *Optic axis*, also called the principal axis of the eye, is the axis of its figure. It is the straight line *h*, Fig. 253, passing through the centre of the pupil and the optic centre of the crystalline lens.

3d. *Optic angle*, is that formed between the two optic axes when the eyes are directed towards the same point. It is less and less as the object is more and more distant.

4th. *Visual angle*, is the angle A O B formed between secondary axes drawn from the optic centre O of crystalline lens to the outer limits of the object. It increases with its magnitude, and diminishes with its distance, as in Fig. 254, in which the angle subtended is much greater at A B than at A′ B′. If the visual

FIG. 254.



Visual angle.

angle is less than half a minute, the true form of an object cannot be discerned. A white square of one yard on each edge, at a distance of five miles, appears as a bright spot, not distinguishable from a circle of that diameter placed at the same distance.

560. Accommodation.—By this is meant the adjustment of the optical mechanism until images of objects at different distances are brought to an accurate focus on the screen of the eye. There are three ways by which this can be accomplished:

1st. *The elongation of the apparatus* in its principal axis, and

thereby moving the screen further from the cornea. The method would be similar to that adopted in an ordinary camera obscura. The manner in which the result was imagined to be attained was, that when the recti muscles all acted together, they compressed the zone of the ball to which they were attached, causing it to be elongated from before backwards, and assume an egg-shape. This is now abandoned.

2d. *Change in distance between the crystalline lens and the screen.* It having been satisfactorily shown that the eyeball does not change its figure, it was then stated that the result was attained by moving the lens towards or from the screen. This, it was supposed, was accomplished by action of the ciliary muscle.

3d. *Change in curvature of the lens.* That this certainly takes place is proven by the following experiment: Take a young person with normal vision, hold a lighted candle in front and a little to one side of one of his eyes. Look into his eye from the opposite side, three images of the candle flame will be seen: the first very bright and erect, this is produced by reflection from the cornea; the second not so bright, also erect, comes from the anterior surface of the lens; the third fainter, is inverted, and is from the posterior surface of the lens. Direct the person to look into remote distance. Observe accurately the relative size and position of the images. Then let him change the point of observation to an imaginary object close at hand, but in the same line of light as before, it will at once be noticed that the first and third images do not change, while the second alters its position and grows smaller. It is, therefore, evident, that the anterior surface of the lens has changed its figure, and become more convex, as it is this which forms the image. These differences are represented in Fig. 255, in which the lens is

Fig. 255.

Accommodation.

divided by a line which shows on one side, F, the condition when the point of vision is *far* off, and on the other, N, when it is *near*. *a* is the aqueous humor, *d* ciliary muscle, *e* ciliary process.

Helmholtz thinks that the manner in which the change in figure is accomplished is as follows: "The lens is invested by a thin, transparent membrane, which extends outwards from its edge as a circular curtain, and is attached all around to the

sclerotic. This membrane is naturally drawn tight by the elastic rigidity of the sclerotic, and presses gently on the elastic lens, flattening it slightly. This is the normal passive condition, as when gazing at a distance. Now there are certain muscular fibres (ciliary muscle) which, arising from the exterior fixed border of the iris just where it is attached to the sclerotic, run backward, radiating, and take hold upon the outer edge of the lens curtain. When these contract, they pull forward the tense curtain to a smaller portion of the globe, and thus relax its tension. This relaxing, relieves also the pressure of the capsule on the lens, which, therefore, immediately swells or thickens in proportion to the dêgree of relaxation." According to Helmholtz, then, *we adjust the eye to near objects by contraction of the ciliary muscle.*

The normal eye in a passive state is adjusted to infinitely distant objects. By change of form of the lens, it can adjust itself to all distances up to about five inches. The range of adjustment or of distinct vision is, therefore, within these limits. It is only at comparatively near distances, however, that the change is great. Between twenty feet and infinity the adjustment is almost imperceptible.

561. Normal Action of Optical Mechanism.—The following phenomena present themselves in connection with this subject; some purely optical, others partly or wholly connected with the nervous mechanism.

1st. The image of the object is formed at its conjugate foci.

2d. The images are inverted.

3d. The eye is not an achromatic apparatus in the usual acceptation of the term, since the refractions are all in the same direction. The experiments of Müller, Young, and others, have shown that neither is it so in an absolute sense. In spite of this, we nevertheless see objects free from chromatism. Ganot says: "The cause of this achromatism cannot be accurately stated."

4th. The best visual distance for small objects, as fine print, is ten or twelve inches. This is called normal vision.

Fig. 256.

Irradiation.

5th. The accommodation for differences in distance by means of the suspensory ligament and ciliary muscle is perfect, while the eye is in the normal state.

6th. Irradiation. White or bright objects appear larger than they really are, when viewed on a dark ground. A white square on a black ground seems to be larger than a black square of exactly the same size viewed on a white ground.

562. Abnormal Action of Optical Mechanism.—The term *emmetropy* is employed to indicate the perfect acting or normal eye. In it the focus ranges from five inches to infinity. If removed from the orbit, it is found to be adjusted for objects at an infinite distance. To adjust it for those nearer requires muscular effort. From this perfect condition we find the following departures, some depending upon imperfect construction, and others upon functional derangement.

1st. *Myopy*, or near-sightedness, is a structural defect. Owing to excessive refractive power, the focus for objects at a great distance falls in front of the retina instead of on it. The rays when they reach it are divergent, and to form a sharp image the object must be brought nearer. In the emmetropic eye the range of vision is from five inches to infinity; in the myopic, from one inch to five, from three inches to a yard, or between any other two fixed points. Within these limits the property of adjustment is as perfect as in the normal eye.

The myopic eye has been compared to a camera used for taking objects close at hand, and when shortened as much as possible is still too long to bring those at a distance to a focus on the ground glass.

2d. *Presbyopy*, or old-sightedness, sometimes incorrectly called long-sightedness, is a functional disease. In it the power of adjustment for near objects is lost, or impaired. In other respects it is normal. The focus for distant objects, or for parallel rays, is on the retina. As far as known, the trouble is a want of elasticity in the crystalline lens, whereby it fails to become more convex, or shortens its focus when the ciliary muscle relaxes the tension of its curtain.

The presbyopic eye resembles a camera made to bring distant objects to a focus on the ground glass, but by misuse or rust the adjustment apparatus fails to focus those which are near.

3d. *Hypermetropy* is a structural defect; it is the true reverse of myopy. In it the refractive power of the lens is below normal, and parallel rays are brought to a focus beyond the black pigment instead of on it. While the power of adjustment is perfect, objects at a distance are brought to a sharp focus on the retina, but this is not possible with those near at hand.

Le Conte likens the hypermetropic eye to a camera, which when entirely pushed up is too short for imaging any objects; when drawn out will bring distant ones to a focus, but not those near at hand.

4th. *Astigmatism* is a structural defect. In it the curvatures of the lenses are not symmetrical. An upper or a lateral half of the lens, or cornea, is not exactly like the opposite half. The rays are consequently not brought to a focal point but to

a line. They may be brought to two separate foci, thus constituting *diplopy*, or double vision. Diplopy also arises from the concerted action of two dissimilar eyes.

563. Spectacles are convergent or divergent lenses of glass or quartz made for correcting forms of abnormal vision. Each requires its proper kind of lens.

1st. *Myopy* requires concave or divergent glasses, which just correct the excessive refraction action of the eye. The trouble being structural, they should be worn habitually.

2d. *Presbyopy* needs convex glasses to bring objects near at hand to a focus. When those at a distance are examined they are removed. They should not be worn habitually, but only when examining objects close at hand. In very old people, when the curvature of the lenses diminishes, it frequently becomes necessary to use convex lenses for distant objects.

3d. *Hypermetropy* necessitates the habitual use of convex spectacles to make the action normal. As age advances, two pairs are requisite, one for distant objects, and one for those close at hand.

4th. *Astigmatism.* In this the curvatures of the different parts of the eye not being alike, compound sectional lenses must be arranged which correct these departures from the normal, and produce on the retina a single well-defined image. When the diplopy depends upon a simple difference between the eyes, it can be corrected by selecting a lens for each independently of the other.

Spectacles were formerly made either from double convex or double concave lenses. These have now been replaced by the concave or convex meniscus (527), placed with their curvature in the same direction as that of the eye. By these so-called *periscopic glasses* a wider range of vision is attained.

In closing this article on spectacles, we give the following excellent advice from an eminent writer:

"Men engaged in literary pursuits should read most by day and write most by night. It is worthy of note that reading causes more strain to the eye than writing, and that copying work in writing makes a greater demand upon the organ of vision than off-hand composition. Twilight and a mixture of twilight and artificial illumination should be avoided for any kind of work. The pale cobalt-blue tint is the best that can be employed when protection for the eye from intense glare is sought, as in the case of travelling upon snow-fields in bright sunshine. The green glass that is often adopted for this purpose is not by any means so worthy of confidence. Reading in railway travelling is objectionable in the highest degree for a very obvious reason. The oscillation of the carriage continually

alters the distance of the page from the eye, and so calls for unceasing strain in the effort to keep the organ in due accommodation for the ever-varying distance of the dancing image."

"The exact fitting of the framework of spectacles to the face and eyes is of more importance than is generally conceived. If the centres of the lenses of the spectacles do not accurately coincide with the centres of the pupils of the eyes, the consequence is that the images in the separate eyes are a little displaced from the positions which they ought to hold, and that a somewhat painful and injurious effort has to be made by the eye to bring those images back into due correspondence for accurate vision. An incipient squint is apt to be in this way produced. People should look to the centring of their spectacles for themselves. This may be easily done by standing before a looking-glass with the spectacles in their place. If the fit is a good one, the centre of the pupil should then appear in the centre of the rim. Fully formed spectacles are always to be preferred to folding frames, because they permit of more satisfactory adjustment in this particular, and because they are more easily kept in the right position with regard to the eyes. The only advantage which the pebble or quartz enjoys over glass for the construction of spectacles is the immunity which it possesses against scratching on account of its greater hardness."

564. Binocular Vision.—Hold a six-sided pencil vertically at a distance of ten inches from the eye, and view it first with the right, and then with the left. A difference is perceived in each case, the right seeing more or further on the right side, while the left sees further on the left side. The image produced is really flat, and presents only two dimensions, length and breadth, as in a picture. When we view the object with both eyes, the two images are blended into one, and the impression of relief, depth, or the third element of space is produced.

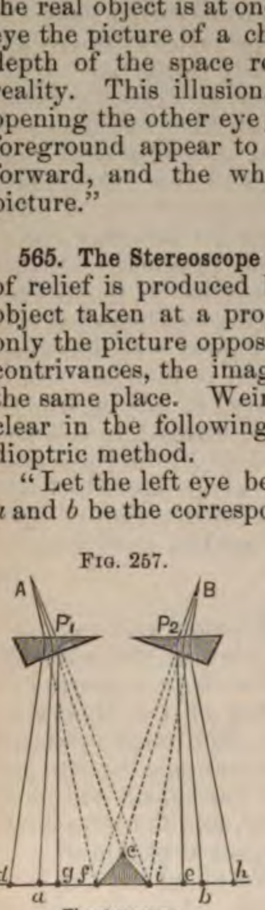
Regarding the impression of relief, Weinhold says, "It is true that we scarcely fail to perceive this when we look at objects with one eye shut, but this is the result of a rapid mental process of which we have become unconscious in consequence of our constant experience of the succession of things in depth. Still our estimation of depth in space is not trustworthy if we rely on the information conveyed by one eye only. An accurately drawn picture of an object makes the same impression upon a single eye, at least as regards the external form, as the object itself, for one eye is as little able to estimate directly the relative distances of the various parts of the object as the picture is of giving a direct representation of these distances. As a consequence of this, a picture produces the greatest resemblance to reality when viewed with one eye only; as soon as the other

eye is opened, the picture presents of course the same aspect to either eye, and the difference between it and the appearance of the real object is at once detected. Thus after viewing with one eye the picture of a church interior, or of a row of pillars, the depth of the space represented will make the impression of reality. This illusion, however, will at once be destroyed on opening the other eye; the parts of the picture which form the foreground appear to recede, the background seems to move forward, and the whole merges into the flat surface of the picture."

565. The Stereoscope is an instrument by which the impression of relief is produced by a combination of two pictures of any object taken at a proper angle to each other. Each eye sees only the picture opposite it, but by suitable catoptric or dioptric contrivances, the images are made to coincide, and appear in the same place. Weinhold makes the principle involved very clear in the following diagram and explanation based on the dioptric method.

"Let the left eye be at A, Fig. 257, and the right at B; let *a* and *b* be the corresponding pictures for each eye, and P_1 and P_2 two prisms of glass through which they are seen. A prism refracts rays of light so that objects viewed through it appear to be nearer to the refracting edge; the prism P_1, therefore, refracts the ray $a\,P_1$ in the direction $P_1\,A$, as if it proceeded from *c*. The prism P_2 refracts the ray $b\,P_2$, so that to the eye at B it also appears to proceed from *c*. The effect of this is—provided that the two pictures, *a* and *b*, are drawn just as a body at *c* would appear to the eyes at A and B, if the prisms were not there—that the object really appears to be at *c*. And as the points *a* and *b* combine to form the point *c*, so *d* and *e* unite to form the point *f*, *g* and *h* to form the point *i*."

FIG. 257.



The stereoscope

Similar effects of relief may be produced by the projection on the same spot of two photographic images of any object taken at a suitable angle to each other.

566. Size and Distance of Objects.—Our estimation of these depends: 1st, upon comparison with those of known size in the same locality; 2d, upon the visual angle; 3d, upon the optic angle. Regarding the latter, Ganot says: "This angle increasing or diminishing according as objects approach or recede, we

move our eyes so as to make their optic axes converge towards the object which we are looking at, and thus obtain an idea of its distance. Nevertheless, it is only by long custom that we can establish a relation between our distance from the objects and the corresponding motion of the eyes. It is a curious fact that persons born blind, whose sight has been restored by an operation for cataract, imagine at first that all objects are at same distance."

The phenomena presented by the action of the retina appertain rather to physiology than to physics. An admirable discussion of these and of all matters connected with vision will be found in Le Conte's book on "Sight."

CHAPTER XXVI.

THE MICROSCOPE AND THE TELESCOPE.

The simple microscope—The compound microscope—Parts of modern microscope—Dry objectives—Immersion objectives—Choosing and testing objectives—Eye-pieces—Tube and accessories—The body—The stage—Focussing apparatus—The stand or foot—Illumination—Simple axial illumination—Diaphragms—Condensed axial illumination—Oblique illumination—Reflected illumination—Polarized illumination—Sources of illumination—Augmentation of magnifying power—Measurement of magnifying power—Care of microscope—Care of the eyes—Errors in interpretation—Non-vital motion—Binocular and chemical microscopes—Fixation of images—Preparation of slides and covers—Preparation of objects—Hardening and section-cutting—Simple microtome—Injection—Staining—Chemical testing—Preservative medium—The microscope and disease germs—Telescope.

THE microscope and the telescope are instruments which depend upon refraction for their action. Their function is to assist normal vision. The former, as its name indicates, enables us to find and magnify minute objects, and determine their structure and the relation of their parts to each other. The latter, to discover and satisfactorily examine objects at a distance.

To physicians, the microscope is by far the more important of these instruments, and since the requirements of modern medicine demand not only a knowledge of its parts and their use, but also the methods of preparing various objects for examination, a brief description of these has been given in the latter part of this Chapter.

567. The Simple Microscope consists of a convex lens (528) of short focus, suitably mounted; it is often called a magnifying glass, and is commonly used as a dissecting microscope. The object is placed between the lens and its principal focus (530), when an erect and magnified image (534, 535) is produced. A very good impromptu instrument may be formed by making a circular hole in a piece of thin metal, card-board, or wood, and suspending a small drop of clear water in the aperture.

In the earliest and simplest forms, the lens is a double-convex of equal curvatures; there is consequently serious spherical (536) and chromatic aberration (538) in the image. To reduce the *spherical aberration* diaphragms and stops (542) are employed. It is also greatly diminished by the use of two plano-convex lenses, with the plane faces turned towards the object. Improved definition under equal power is thus gained with moderate loss of illumination. This combination is known as the Wollaston doublet. Other methods are described in (536).

Chromatic aberration may be avoided, when desired, by the use of an achromatic lens (539).

The distinctness of the image depends largely on the position of the eye. The object and eye should be in the line of the principal axis of the lens (526) and maintained at the proper focal distance.

The *magnifying power* is usually measured in diameters or linear increase. It is the ratio of the apparent to the real diameter of the object, both being viewed at the same distance. Working powers as high as 120 diameters are reached in simple microscopes. Magnifying power is also measured in terms of the focal distance of the lens, *e. g.*, two inch, half inch, etc., the greater power belonging to that of shorter focus.

When used for dissection the lens is generally mounted in some form of stand. "Lenses most serviceable for hand magnifiers range in focal length from two inches to half an inch; and a combination of two or three in the same handle with an intervening perforated plate of tortoise-shell (which serves as a diaphragm when used together) will be found very useful. When such a magnifying power is desired as would require a lens of a quarter of an inch focus, it is best obtained by the substitution of a 'Coddington.'"

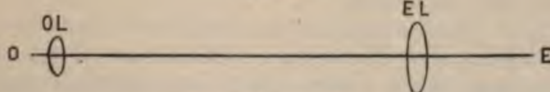
The *Coddington lens.* "The first idea of this was given by Dr. Wollaston, who proposed to apply two plano-convex or hemispherical lenses by their plane sides with a 'stop' interposed, the central aperture of which should be equal to one-fifth of the focal length. The great advantage of such a lens is, that the oblique pencils pass, like the central ones, at right-angles to the surface, so that they are but little subject to aberration. The idea was further improved upon by Sir D. Brewster, who pointed

out that the same end would be much better answered by taking a sphere of glass and grinding a deep groove in its equatorial part, which should be then filled with opaque matter, so as to limit the central aperture. Such a lens gives a large field of view, admits a considerable amount of light, and is equally good in all directions, but its power of definition is by no means equal to that of an achromatic lens, or even of a doublet. This form is chiefly useful, therefore, as a hand magnifier, in which neither high power nor perfect definition is required; its peculiar qualities rendering it superior to an ordinary lens for the class of objects for which a hand magnifier of medium power is required. Many of the magnifiers sold as 'Coddington' lenses, however, are not really portions of spheres, but manufactured out of ordinary double-convex lenses, and, therefore, destitute of the special advantages of the real 'Coddington.'"

The *Stanhope lens* somewhat resembles the preceding in appearance, but differs from it essentially in properties. It is nothing more than a double-convex, having two surfaces of unequal curvatures, separated from each other by a considerable thickness of glass; their distances so adjusted, that when the most convex is turned towards the eye, minute objects placed *on* the other shall be in the focus of the lens.

568. The Compound Microscope in its simplest form consists of two convex lenses, Fig. 258, one O L, of short, and the other,

FIG. 258.



Compound microscope.

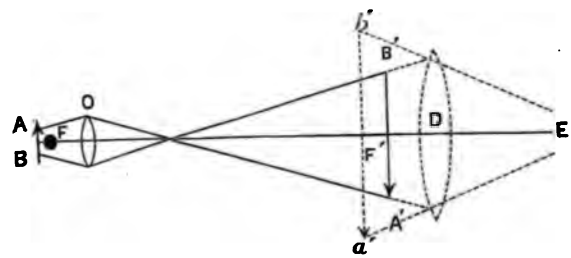
E L, of long focus, mounted on the same optical axis O E. The shorter focus is placed near the object O; it is, therefore, called the *objective*. The image formed by this is viewed through the other, E L, by the eye placed at E; it is called the *eye-piece*.

The principle involved in the action of the compound microscope is illustrated in Fig. 259. The object A B is placed a little further from the objective O than its focal distance F; a real image magnified and inverted is produced on the opposite side of the lens at A′ B′. This is viewed at E through the second lens D in such a way that it is between the lens D and its focus F′. Thus examined, a virtual and still further magnified image is seen at a' b'.

The final image a' b' is erect as regards A′ B′, but inverted as

regards the object A B. A compound microscope, therefore, is a "simple microscope applied not to the object, but to its image already magnified by the first lens."

FIG. 259.

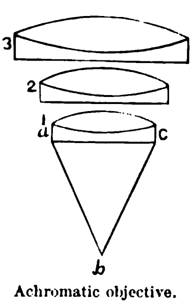


Relation of eye-piece and objective.

569. Parts of a Modern Microscope.—From the simplest form, great departures have been made, which render it necessary to take up the consideration of the several parts of the instrument. It is to be remembered, however, that in all cases the principles involved remain the same as in that already described. The parts may be discussed in the following order: 1st. Objectives, both dry and immersion. 2d. The eye-piece. 3d. The shaft or tube, with the attached parts. 4th. The stage. 5th. The methods of illumination. 6th. The source of illumination. 7th. Arrangement of magnifying power. To these, miscellaneous subjects relating to the care of the instrument, preparation of objects, etc., may be added.

570. Dry Objectives.—The simple double-convex lens, described in (568), has long since given way to objectives of greater and greater complexity of structure. This has been found necessary in order to obtain the high magnifying powers required in biological and other researches. Not only are all microscopes now fitted with achromatic objectives, but these are sometimes made up of a number of such lenses. In Fig. 260 an objective of this character, consisting of three achromatic lenses, 1, 2, 3, each composed of a double-convex crown, and a plano-convex flint is represented. In addition to an increase in the number of lenses, contrivances for changing their distance from each other are added, whereby corrections for thickness of cover on the object are made. *a b c* represents the angular aperture.

FIG. 260.



Achromatic objective.

While greater perfection is theoretically attained by increase

in the number of lenses, there is an additional loss of light by virtue of the numerous surfaces and media through which it is obliged to pass. In the objective we have described there are twelve surfaces to be accurately ground, and fitted to each other. This implies considerable liability to imperfection in workmanship; the fewer the surfaces, the less the liability to error as well as the less the loss of light. To gain the advantages arising from a smaller number of lenses, Amice substituted a single plano-convex of crown glass in the front combination, thus reducing the surfaces to ten. This has again been modified by adding a lens to the back-combination. Such objectives consist of two flint-concaves and four crown-convexes. In more recent combinations, the chromatic correction is made "entirely in the middle lens by a double-concave of dense flint between two convexes of crown, both back and front lenses being simple plano-convexes of crown; the surfaces have thus been again reduced to ten."

No objective of a given power can do all the work required of it to perfection. Especially is this so with high powers. The following qualities are involved in the action of a microscope objective.

1st. *Magnifying power.* This has been discussed in the simple microscope (567).

2d. *Angle of aperture* and *numerical aperture.* The first of these has been described in article (526). It is also shown at *a b c* in the achromatic combination, Fig. 260. Regarding Professor Abbe's system of numerical aperture, Professor Carpenter writes:

"It can be easily demonstrated mathematically, that the 'aperture' of a single lens used as a magnifying glass—that is, its capacity for receiving and bringing to a remote conjugate focus, the rays emanating from the axial point of an object brought very near to it—is determined by the ratio between its absolute diameter (or clear 'opening') and its focal length; while that of an ordinary achromatic objective, composed of several lenses, is determined by the ratio of the diameter of its *back* lens (so far as this is really utilized) to its focal length.

"When, however, the medium in which the objective works is not air, but a liquid of higher refractive index—such as water or oil—an additional circumstance has to be taken into consideration; for we may now have three *angles* of aperture expressed by the *same* number of degrees, which yet denote quite different 'apertures.' For instance, an 'angle' of 90° in oil will give a greater 'aperture' than one of 90° in water; and the latter a greater aperture than 90° in air.

"Taking as a standard of comparison a 'dry' objective of the maximum theoretical angle of 180°, whose numerical aperture

is the sine of 90°,=radius or 1.00, we find this standard to be equalled by a 'water' immersion objective of only 96°, and by an 'oil' or 'homogeneous' immersion lens of only 82°; the '*numerical apertures' of these, obtained by multiplying the sines of their respective semi-angles by the refractive index of water in one case and of oil in the other, being* 1.00 *in both.* Each, therefore, will have as great a power of receiving and utilizing divergent rays, as any 'dry' lens can even theoretically possess,—an angle of nearly 70° being the limit of what is practically attainable. But as the actual angle of an 'immersion' objective can be opened out to the same extent as that of an 'air' objective, it follows that the 'aperture' of the former can be augmented *far beyond* even the theoretical maximum of the latter; the maxima of numerical aperture being 1.52 for oil-immersion, and 1.33 for water-immersion objectives, as against 1.00 for 'dry;' and these being nearly attainable in practice.

"This important doctrine may be best made practically intelligible by a comparison, Fig. 261, of the relative diameters of the *back* lenses of 'dry' with those of 'water' and 'oil' immersion objectives of *the same power*, from an 'air-angle' of 60° to an 'oil-angle' of 180°; these diameters expressing in each case the opening between the extreme pencil-forming rays at their issue from the posterior surface of the combination, to meet in their conjugate foci for the formation of the image; *the extent of which opening in relation to focal length* (not that of the rays entering the objective) *is the real measure of the aperture of the combination.* The dotted circles in the interior of 1 and 2 are of the same diameter as 3; and, therefore, show the excess in the diameters of the back lenses of the 'oil' and 'water' immersion-objectives, over that of the 'dry' at their respective theoretical limits.

"A wide-angled 'immersion' objective can utilize rays from an object mounted in a dense medium, such as balsam, which are entirely *lost* when the same object is in air, or is observed through a film of air. And this loss cannot be compensated for by an increase of illumination; because the rays which are lost are *different* rays, physically, from those obtained by any illumination, however intense, in a medium like air.

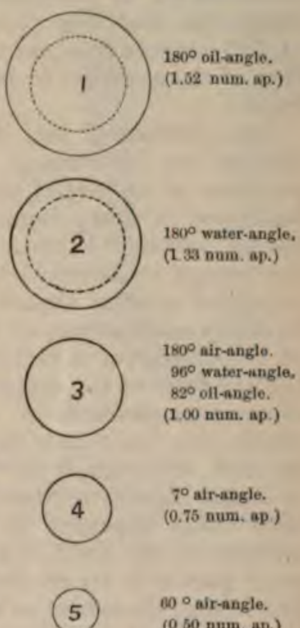
"It is by increasing the number of 'diffraction spectra,' that the rays admitted from the object contribute to the 'resolving power' of the objective for lined and dotted objects; the truth of the image formed by the recombination of these spectra being, as formerly shown, essentially dependent upon the augmentation of the number which the objective can be made to receive.

"Upon the 'aperture' of an objective are dependent (1) its illuminating power, (2) its resolving power, and (3) its penetrating power;—the first varying as the square of the numerical

aperture, the second being in *direct*, and the third in *inverse* proportion to the numerical aperture."

3d. *Working distance* is the actual space between the front element of the objective and the object. It does not bear a fixed relation to the focal length, for while this is equal to the magnifying power of a single lens of given curvature, the working distance depends upon the manner in which the parts or elements of the combination are constructed, and upon its angular aperture. Increase is not only of advantage in securing side illumination, but of vital importance in the highest powers to gain sufficient space for the covering glass, as well as for attaining the required penetration and resolving properties.

FIG. 261.



Numerical aperture.

4th. *Defining power* depends upon the perfection of the correction for spherical and chromatic aberration, especially upon the first. In immersion lenses finer results may be attained with wide angle lenses than in the dry system. The character of the eye-piece exercises an important influence on this quality, and should always be taken into consideration in forming a correct judgment of defining power. The estimation of this is obtained by comparing the action of different lenses upon some object with which the examiner is familiar.

5th. *Penetrating power*, or focal depth, is the vertical depth above and below the true focal plane through which objects may be defined with sufficient clearness to make out their correct relations to others in that plane. In opaque objects this quality is of the utmost importance. In watching the actions in a living organism, as amœba, it is also essential. In an exceedingly thin membrane, on the contrary, all portions being nearly in the same plane, it is objectionable, since it demands a certain sacrifice in sharpness of definition. As a rule, it may be said, that objectives of the longest working distance have the greatest penetration, while those of wider aperture have lower.

6th. *Resolving power* is the property of separating and clearly defining very closely placed dots or lines. It strengthens with increase in angular aperture, not on account of the greater obliquity of the rays entering the lens, but of its power to recom-

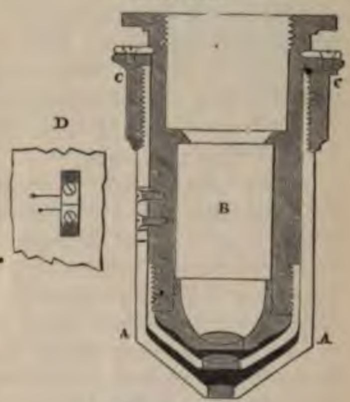
bine the diffraction spectra produced. For the best working of the lens in the resolution of surface markings, the proper degree of obliquity must be given to the illumination. When, on the contrary, it is desired to determine special points in relation to internal structure, as the process of division in cell-nuclei, axial illumination is preferable. Prof. Abbe has shown that the maximum resolving power attainable with an angular aperture of 180 degrees is equal to 118,000 lines to the inch. A reduction of the aperture to 106 degrees, lowers the number to about 94,000.

7th. *Flatness of field* determines the practical extent of the field of the instrument. With some objectives the marginal portions of an object are indistinguishable, while the central parts are in sharp focus. Regarding this property, Prof. Carpenter writes: "With a really good objective, not only should the image be distinct even to the margin of the field, but the marginal portion should be as free from color as the central. In many microscopes of inferior construction, the imperfection of the objectives in this respect is masked by the contraction of the aperture of the diaphragm in the eye-piece which limits the dimensions of the field; and the performance of one objective within this limit may scarcely be distinguishable from that of another, although, if the two were compared under an eye-piece of larger aperture, their difference of excellence would be at once made apparent by the perfect correctness of one to the margin of the field, and by the entire failure of the other in every part save its centre. In estimating the relative merits of two lenses, therefore, as regards this condition, the comparison should be made under an eye-piece giving a larger field."

8th. *Cover adjustment.* Again we quote from the same authority: "When objectives of short focus and of wide angular aperture are in use, something more is necessary (save in the case of 'homogeneous-immersion' lenses) than exact focal adjustment; this being the *adjustment of the objective* itself, which is required to neutralize the disturbing effect of the glass cover upon the course of the rays proceeding from the object,—unless (as in the objectives now commonly made for students' microscopes) they are constructed for working *only* with cover-glasses of a certain standard thickness. For such adjustment, it will be recollected, a power of altering the distance between the front pair and the remainder of the combination is required; and this power is obtained in the following manner: The front pair of lenses is fixed into a tube, Fig. 262, A, which slides over an interior tube, B, by which the other two pairs are held; and it is drawn up or down by means of a collar, C, which works in a furrow cut in the inner tube, and upon a screw-thread cut in the outer, so that its revolution in the plane to which it is fixed

by the one tube gives a vertical movement to the other. In one part of the outer tube an oblong slit is made, as seen at D, into which projects a small tongue screwed on the inner tube; at the side of the former two horizontal lines are engraved, one pointing to the word 'uncovered,' the other to the word 'covered;' whilst the latter is crossed by a horizontal mark, which is brought to coincide with either of the two lines by the rotation of the screw-collar, whereby the outer tube is moved up or down. When the mark has been made to point to the line 'uncovered,' it indicates that the distance of the lenses of the object-glass is such as to make it suitable for viewing an object without any interference from thin glass; when, on the other hand, the mark has been brought by the revolution of the screw-collar into coincidence with the line 'covered,' it indicates that the front lens has been brought into such proximity with the other two, as to produce a 'positive aberration' in the objective, fitted to neutralize the 'negative aberration' produced by the interposition of a glass cover of extremist thickness. But unless this correction be made with the greatest precision to the thickness of the particular cover in use, the enlargement of the angle of aperture, to which opticians have of late applied themselves with such remarkable success, becomes worse than useless; being a source of diminished instead of increased distinctness in the details of the object, which are far better seen with an objective of greatly inferior aperture, possessing no special adjustment for the thickness of the glass. The following general rule is given by Mr. Wenham for securing the most efficient performance of an object glass with any ordinary object: 'Select any dark speck or opaque portion of the object, and bring the outline into perfect focus; then lay the finger on the milled-head of the fine motion, and move it briskly backwards and forwards in both directions from the first position. Observe the expansion of the dark outline of the object, both when within and when without the focus. If the greater expansion, or coma (537), is when the object is *without* the focus, or furthest from the objective, the lenses must be placed further asunder, or towards the mark 'uncovered.' If the greater coma is when the object is *within* the focus, or nearest to the objective, the lenses must be brought closer together, or towards

FIG. 262.



Adjustment for cover.

the mark 'covered.' When the object-glass is in proper adjustment, the expansion of the outline is exactly the same both within and without the focus.'"

571. Immersion Objectives.—Amici first showed that the intervention of a drop of water between the object, or its covering glass, and the front lens of the objective, greatly diminished the loss of light. This was afterwards utilized by Hartnack and Nachet, in the construction of the so-called *immersion-lenses* of high power and wide aperture. In discussing this system Prof. Carpenter says:

"The loss of light increases with the obliquity of the incident rays; so that when objectives of very wide angle of aperture are used 'dry,' the advantages of its increase are in great degree nullified by the reflection of a large proportion of the rays falling very obliquely upon the peripheral portion of the front lens. When, on the other hand, rays of the same obliquity enter the peripheral portion of the lens from water, the loss by reflection is greatly reduced, and the benefit derivable from the large aperture is proportionally augmented. Again, the '*immersion system*' allows of a greater working distance between the objective and the object than is otherwise attainable with the same extent of angular aperture; and this is a great advantage, not merely in regard to convenience in manipulation, but also in giving a greater range of penetration or 'focal depth.' Further, the observer is rendered less dependent upon the exactness in the correction for the thickness of the covering-glass, which is needed where objectives of large angle are used 'dry,' for as the amount of 'negative aberration' is far smaller when the rays which emerge from the covering-glass pass into water, than when they pass into air, variations in its thickness produce a much less disturbing effect. And thus it is found practically that 'immersion' objectives can be constructed with magnifying powers sufficiently high, and angular apertures sufficiently large, for all the ordinary purposes of scientific investigation, without any necessity for cover adjustment; being originally adapted to give the best results with a covering-glass of suitable thinness, and small departures from this in either direction occasioning very little deterioration in their performance. For 'water-immersion' objectives of the very largest aperture, however, to be used upon the most difficult objects, exact cover-correction is still necessary. Whilst 'immersion' objectives constructed on the original plan can only be employed 'wet' (that is, with the interposition of water), Messrs. Powell and Lealand, followed by other makers, have so arranged their combinations, that by a change in the front lens they may be used 'dry,' as in the ordinary manner. And in Mr. Wenham's system not even this

change is required, the change from 'wet' to 'dry,' and *vice versa*, being accomplished by an alteration in the distance of the front lens from the middle triplet, made by the screw collar, as in ordinary cover-correction."

"*Homogeneous immersion* consists in the replacement of the water previously interposed between the covering-glass and the front surface of the objective, by a liquid having the same refractive and dispersive power as crown-glass; so that the rays issuing at any angle from the upper plane surface of the covering-glass, shall enter the plane front of the objective without any change either by refraction or dispersion, and without any sensible loss by reflection—even the most oblique rays proceeding in their undeflected course, until they meet the convex back surface of the front lens. It is obvious that all the advantages derivable from the system of *water* immersion are obtainable with still greater completeness by this system of *homogeneous* immersion, provided that a fluid can be found which meets its requirements. After a long course of experiments, Prof. Abbe discovered that *oil of cedar-wood* so nearly corresponds with glass, alike in refractive and in dispersive power, that it serves the purpose extremely well, except when it is desired to take special advantage of the most divergent or marginal rays, *oil of fennel* being then preferable. Objectives of $\frac{1}{8}$th, $\frac{1}{12}$th, and $\frac{1}{18}$th inch focal length have been constructed on this plan by Zeiss; and it appears certain that by its means a larger angle of aperture can be effectively obtained than on any other construction. Whether any tests can be resolved by its use, on which other objectives fail, is a point not yet satisfactorily determined. But there can be no doubt that the system of 'homogeneous immersion' will greatly facilitate the use of objectives possessing the largest angular aperture, and capable of affording the highest magnifying power for the ordinary purpose of scientific research. It is precisely in the case of such objectives that the 'cover-correction' needs to be most exact. And although the practised microscopist has no difficulty in making this, when the object at which he is looking (such as a Diatom, a Podura-scale, or a band of Nobert's ruled lines) is *known* to him, yet the case is entirely different when the object is altogether *unknown*. For in examining such an object he may be only able to satisfy himself after repeated trials, involving much expenditure of time and patience as to the cover-correction which gives the truest representation of the object; whilst, in using a 'homogeneous' or 'oil-immersion' objective, he is able to feel an absolute certainty that, without any adjustment at all, the view which he gains of an unknown object is in every respect at least equal to that which he can obtain from the best 'dry' or 'water-immersion' objective, most exactly adjusted for thickness of cover."

572. Choosing and Testing Objectives.—"The most perfect objective for general purposes is obviously that which combines *all* the preceding attributes in the degree in which they are mutually compatible. But it seems to be now clear that the highest perfection of the two primary qualities, 'defining power' and 'resolving power,' cannot be obtained in the same combination; so that the choice between two objectives, one distinguished by the former of these, and the other by the latter, will depend upon the work on which it is employed.

"In estimating the value of an object-glass, it should always be considered *for what purpose it is intended;* and its merits judged of according to the degree in which it fulfils that purpose. We shall, therefore, consider what are the objects proper to the several 'powers' of object-glasses—*low*, *medium*, and *high;* and what are the objects by its mode of exhibiting which each may be fairly judged.

"By objectives of *low* power we may understand any whose focal length is greater than *half an inch;* they give a range of amplification of from 10 to 70 diameters with the A eye-piece, and of from 16 to 120 diameters with the B eye-piece. An 'adjustable' low power is made by Zeiss, of Jena, in which, by varying the position of the front lens by means of a screw-collar, a *range* of power is obtainable from about 8 to 16 diameters with the A eye-piece, and from 12 to 24 with the B eye-piece. Objectives of *low power* are most used in the examination of opaque objects, and of transparent objects of large size and of comparatively coarse texture; and the qualities most desirable in them are a sufficiently large aperture to give a *bright* image, combined with such accurate definition as to give a *clear* image, with 'focal depth' sufficient to prevent any moderate inequalities of surface from seriously interfering with the distinctness of the entire picture, and with perfect 'flatness' of the image when the object itself is flat. The proboscis of the blow-fly is one of the best transparent objects for enabling a practised eye to estimate the general performance of object-glasses of low power; since it is only under a really good lens that all the details of its structure can be well shown. In particular, all the outlines and edges should be seen clearly and sharply, without any haze or fringe; the tracheal spires and rings well-defined, without any color between them.

"We may consider as objectives of *medium power* the half-inch, $\frac{4}{10}$ths inch, $\frac{1}{4}$th inch, and $\frac{1}{5}$th inch; the magnifying power of which ranges from about 90 to 250 diameters under the A eye-piece, and from about 150 to 400 diameters with the B eye-piece. When used by reflected light they can be advantageously employed in the examination of such small *opaque* objects as Diatoms, Polcystines, portions of small feathers, capsules of the

lesser mosses, hairs, etc.; they should be so mounted on cones as to allow of side illumination. The great value of these powers lies in the information they enable us to obtain regarding the details of organized structures, and of living actions, by the examination of properly prepared *transparent* objects by transmitted light. No single object is so useful as the *Podura-scale* for the purpose of testing these qualities in a $\frac{1}{4}$th inch or $\frac{1}{6}$th inch objective; and it may be safely said that a lens which brings out its markings satisfactorily will suit the requirements of the ordinary working microscopist, although it may not resolve difficult Diatoms.

"All object-glasses of less than $\frac{1}{5}$th inch focus may be classed as *high powers*. The magnifying powers which objectives from $\frac{1}{6}$th to $\frac{1}{25}$th inch focus are fitted to, afford range from about 320 to 1250 diameters with the shallower eye-piece, and from 480 to 1850 diameters with the deeper: but by the use of still deeper eye-pieces, or by the objective of $\frac{1}{50}$th inch, or the $\frac{1}{80}$th recently constructed by Messrs. Powell and Lealand, a power of 4000 or more may be obtained. It is seldom, however, that anything is really gained thereby. The introduction of *immersion* lenses has considerably increased the utility of what may be called moderately high powers, such as $\frac{1}{8}$th, $\frac{1}{10}$th, and $\frac{1}{12}$th.

"For resolving power the best tests are afforded by the lines artificially ruled by M. Nobert, and by the more 'difficult' Diatoms. What is known as *Nobert's test* is a plate of glass, on a small space of which, not exceeding $\frac{1}{50}$th of an inch in breadth, are ruled from ten to nineteen series of lines, forming as many separate bands of equal breadth. On the nineteen-band test-plate the lines are ruled at the following distances, expressed in parts of a Paris line, which, to an English inch is usually reckoned as 0.088 to 1.000, or as 11 to 125:

Band 1. 1–1000th.	Band 8. 1–4500th.	Band 14. 1–7500th.
" 2. 1–1500th.	" 9. 1–5000th.	" 15. 1–8000th.
" 3. 1–2000th.	" 10. 1–5500th.	" 16. 1–8500th.
" 4. 1–2500th.	" 11. 1–6000th.	" 17. 1–9000th.
" 5. 1–3000th.	" 12. 1–6500th.	" 18. 1–9500th.
" 6. 1–3500th.	" 13. 1–7000th.	" 19. 1–10000th.
" 7. 1–4000th.		

"The following estimates of the numbers of lines to the English inch, in some of the bands, are given by Dr. Royston Pigott:

Band.	No. of spaces per inch.	Band.	No. of spaces per inch.	Band.	No. of spaces per inch.
I.	11,259	IX.	56,297	XV.	90,076
III.	22,519	XI.	67,557	XVII.	101,335
IV.	33,778	XIII.	78,816	XIX.	112,595
VII.	45,038				

"Prof. Rogers, of Cambridge, has also ruled test-plates which are very accurate in the placement of their lines, and are now in general use.

"The greater part of the Diatoms employed as test objects are comprehended in the genus *Pleurosigma* of Professor Smith; which includes those *Naviculæ* whose 'frustules' are distinguished by their sigmoid (S-like) curvature.

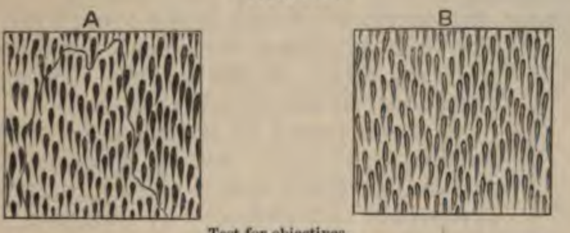
	Direction of striæ.	Striæ in 1-100th of an inch Smith.	Sollitt.
1. Pleurosigma formosum . .	diagonal	34	32—20
2. Pleurosigma strigile . . .	transverse	36	30
3. Pleurosigma Balticum . .	transverse	38	40—20
4. Pleurosigma attenuatum . .	transverse	40	46—35
5. Pleurosigma hippocampus .	transverse	40	45—40
6. Pleurosigma strigosum . .	diagonal	44	80—40
7. Pleurosigma quadratum . .	diagonal	45	60—35
8. Pleurosigma elongatum . .	diagonal	48	
9. Pleurosigma lacustre . .	transverse	48	
10. Pleurosigma angulatum . .	diagonal	52	51—46
11. Pleurosigma æstuarii . . .	diagonal	54	
12. Pleurosigma fasciola . . .	transverse	64	90—50
13. Navicula rhomboides . .	transverse	85	111—60
14. Nitzschia sigmoidea . . .	transverse	85	
15. Amphipleura pellucida (*navicula acus*)	transverse		130—120

"Good specimens of the first ten of the foregoing list may be resolved, with judicious management, by good small-angled $\frac{1}{4}$th or $\frac{1}{8}$th inch objectives, and even, with very oblique illumination, by objectives of $\frac{1}{2}$ and $\frac{4}{10}$th inch, having an angular aperture of ninety degrees; the remainder require the larger aperture proper to the $\frac{1}{8}$th inch or higher power, for the satisfactory exhibition of their markings. The first column of measurements in the above table gives the numbers stated by Professor Smith as *averages;* the second column gives the numbers subsequently assigned as the *extremes* by Mr. Sollitt, who pointed out that great differences exist in the fineness of the markings of specimens of the same species of the Diatom obtained from different localities, a statement now so abundantly confirmed, as to be entitled to rank as an established fact.

"As a test for those qualities of objectives which best fit them for the general purposes of biological investigation, Prof. Carpenter is of the opinion "that nothing is better than the scale of the *Lepidocystus cervicollis*, commonly known as the *Podura.* An objective may serve by virtue of its wide angular aperture, to resolve Diatom-tests of considerable difficulty, and may yet fail utterly on the Podura-scale, in consequence of its inferior defining power; and such an objective can be of very little service to the biological investigator. On the other hand, although the exact *structure* of the Podura-scale is still (like that of the Diatom-valve) a matter of discussion, yet all are agreed as to the *appearances* it presents, under objectives that combine in the fullest degree the attributes already specified as best qualifying them for scientific work; so that any glass which shows these

appearances satisfactorily, may be safely accounted suitable for that purpose. The surface of this scale when viewed under a sufficiently high amplification, is seen to be covered with the peculiar markings shown at A and B, Fig. 263, which are some-

Fig. 263.



Test for objectives.

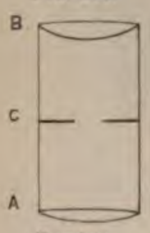
times designated 'spines,' but are more commonly known as 'notes of admiration' or 'exclamation-markings.' These should be clearly separated from each other, and their margins well-defined. An objective of *small* angle (such as a $\frac{1}{4}$th inch of 60°) will show the 'spines' dark throughout, as at A; a $\frac{1}{4}$th inch of 100° will show a light streak extending from the large end, down the centre of each marking; and a further enlargement of the aperture will show an extension of this streak through the entire length of each 'spine,' B. The degree in which these markings retain their brightness and distinctness under deep eye-piecing, may be considered a most valuable test of the excellence of the defining power of the objective. As it is impossible that large-angled objectives used 'dry,' should be perfectly corrected for *spherical* aberration (so as to possess the greatest possible *defining* power) without some residuum of *chromatic* aberration, all the best defining glasses will show the thick part of the spines tinged with either blue or red. Perfect achromatism, on the other hand, is only attainable with 'dry' lenses at some sacrifice of resolving and defining power; and many microscopists prefer to keep the latter to their highest point, even at the expense of complete color-correction. Most physiologists, however, will prefer the highest attainable achromatism at some sacrifice of aperture. *But it is one of the advantages of the 'immersion system' that the residual aberrations of even large-angled objectives can be much more perfectly compensated than they can be in 'dry' objectives; so that on this as on several other accounts, their use is to be recommended whenever permitted by the nature of the research.*"

When the Podura-scale is employed as a test, allowance should be made for the differences existing between different scales. These are as great as with any of the Diatoms. The insect from which this test is derived is commonly known as the "spring-tail" and may be found near decaying wood and in saw-dust.

Two or three objectives are sometimes mounted on a swinging arm called the *nose-piece.* These revolve upon a common axis and one power after another can be quickly brought into the optical axis of the instrument.

573. Eye-pieces.—That in general use consists of two plano-convex lenses, the convexity of each being toward the objective. The lens, A, nearest the objective is called the *field lens;* the other, B, the *eye-lens.* Taken together these form an achromatic combination. This eye-piece was invented by Huyghens for the telescope; he employed it to correct spherical aberration, and did not know that it was achromatic. It was applied to the microscope by Campani. The rays from the objective pass through the field lens before they reach their focus. The image produced under these circumstances is real and chromatic, but when examined by the eye-lens of the combination, the chromatism is corrected, and a still more magnified achromatic virtual image produced. "A diaphragm, C, must be placed between the two lenses in the visual focus of the eye-glass, which is, of course, the position wherein the image of the object will be formed by the rays brought into convergence by their passage through the field-glass."

Fig. 264.



Eye-piece.

"Another advantage of a well-constructed Huyghenian eye-piece is, that the image produced by the meeting of the rays after passing through the field-glass, is by it rendered concave towards the eye-glass instead of convex, so that every part of it may be in focus at the same time, and the field of view thereby rendered flat. Two or more Huyghenian eye-pieces of different magnifying powers, known as A, B, C, etc., are usually supplied with a compound microscope. By some makers the eye-pieces are designated by the focal distance of the combination. The utility of the higher powers will mainly depend upon the excellence of the objectives; for when an achromatic combination of small aperture, which is sufficiently well corrected to perform very tolerably with a 'low' or 'shallow' eye-piece, is used with an eye-piece of higher magnifying power (commonly spoken of as a 'deeper' one), the image may lose more in brightness and in definition than is gained by its amplification; whilst the image given by an objective of large angular aperture and very perfect correction, shall sustain so little loss of light or of definition by 'deep eye-piecing,' that the increase of magnifying power shall be almost clear gain. Hence the modes in which different objectives of the same power, whose performance with shallow eye-pieces is nearly the same, are respectively affected by deep eye-pieces, afford a good test of their respective merits;

since any defect in the corrections is sure to be brought out by the higher amplification of the image, whilst a deficiency of aperture is manifested by the want of light. The working microscopist will generally find the A eye-piece most suitable, B being occasionally employed when a greater power is required to separate details, whilst C and others still deeper are useful for the purpose of testing the goodness of objectives, or for special investigations requiring the highest amplification with objectives of the finest quality. When great penetration or 'focal depth' is required, low objectives and deep eye-pieces will often be found convenient.

"For viewing large flat objects such as transverse sections of wood, under low magnifying powers, the eye-piece known as *Kellner's* may be employed with advantage. In this construction, the field-glass, which is a double-convex lens, is placed in the focus of the eye-glass, without the interposition of a diaphragm; and the eye-glass is an achromatic combination of a plano-concave of flint with a double-convex of crown, which is slightly under-corrected, so as to neutralize the over-correction given to the objectives for use with Huyghenian eye-pieces. A flat, well-illumined field of as much as fourteen inches in diameter may thus be obtained with very little loss of light; but, on the other hand, there is a certain impairment of defining power, which renders the Kellner eye-piece unsuitable for objects presenting minute structural details; and it is an additional objection, that the smallest speck or smear upon the surface of the field-glass is made so unpleasantly obvious, that the most careful cleansing of that surface is required every time this eye-piece is used.

"A *solid eye-piece* made on the principle of the 'Stanhope' lens is sometimes used in place of the ordinary Huyghenian, when high magnifying power is required for testing the performance of objectives. The lower surface, which has the lesser convexity, serves as a 'field-glass;' whilst the image formed by this is magnified by the highly convex upper surface to which the eye is applied; the advantage supposed to be derived from this construction lying in the abolition of the plane surfaces of the two lenses of the ordinary eye-piece."

574. Tube and Accessories.—The *tube* of the instrument serves to maintain the objective and the eye-piece in proper relation to each other in the same optical axis.

The objectives are fitted into the lower end by a screw; a collar with a uniform thread, known as the *society screw*, has been adopted by the majority of makers. By the use of this any objective may be adapted to the instrument. Other special contrivances are sometimes furnished for attachment of very high-angled low powers.

The *eye-piece* is slipped into the upper part, the exterior of its cylinder and the interior of the tube being ground to give a smooth movement.

Diaphragms found in the eye-piece or the tube of a microscope should not be displaced; or if desired to do so, their location should be carefully marked beforehand, in order that they can be replaced in their proper position.

The *draw-tube* is a second tube sliding into the tube proper. While the objective is attached to the latter, the eye-piece is carried by the former. When the former is partly withdrawn the distance between the eye-piece and objective is increased, and greater magnifying power attained.

An *amplifier* is a concave lens interposed between the objective and eye-piece. In the Tolle's form "it is an achromatic concavo-convex lens of small diameter, screwed into the lower end of the draw-tube, so as to be at no great distance behind the objective, the power of which it doubles without producing sensible deterioration of the image. Dr. Devron states that the nineteenth band of a Nobert plate could be resolved by its aid, by objectives under which without it no resolution could be obtained."

The *erector*. "This instrument, first applied to the compound microscope by Mr. Lister, consists of a tube about three inches long, A B, having a meniscus at one end, and a plano-convex lens at the other (the convex sides being upwards in each case), with a diaphragm nearly half-way between them; this is screwed into the lower end of the draw-tube, as shown in Fig. 265 (C D being the eye-piece). Its effect is (like the corresponding erector of the telescope) to antagonize the inversion of the image formed by the object-glass, by producing a second inversion, so as to make the image presented to the eye correspond in position with the object-arrangement. This is of great service in cases in which the object has to be subjected to any kind of manipulation. The passage of the rays through two additional lenses, of course occasions a certain loss of light, and impairment of the distinctness of the image; but this need not be an obstacle to its use for the class of purposes for which it is especially adapted in other respects, since these seldom require a very high degree of defining power. By the position given to the erector, it is made subservient to another purpose of great utility; namely, procuring a very extensive *range* of magnifying power, without

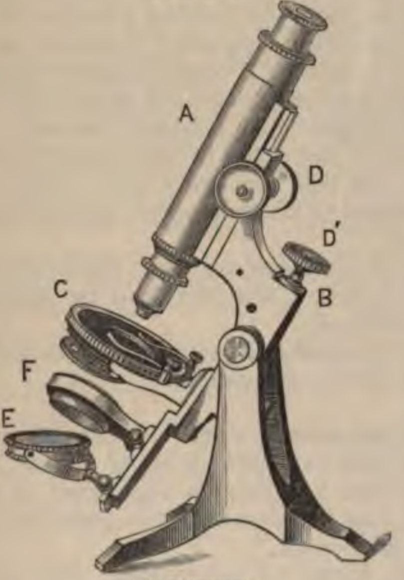
FIG. 265.

Erector.

any change in the objective. For when the draw-tube, with the erector fitted to it, is completely pushed in, the *acting length* (so to speak) is so greatly reduced by the formation of the first image much nearer the objective, that, if a lens of two-thirds of an inch focus be employed, an object of the diameter of $1\frac{1}{2}$ inches can be taken in and enlarged to no more than 4 diameters; whilst, on the other hand, when the tube is drawn out $4\frac{1}{2}$ inches the object is enlarged 100 diameters. Of course, every intermediate range can be obtained by drawing out the tube more or less; and the facility with which this can be accomplished, especially when the draw-tube is furnished with a rack-and-pinion movement (as in Messrs. Beck's Compound Dissecting Microscope), renders such an instrument very useful in research."

575. The Body.—B carries the tube A, just described, with objective and eye-piece; the stage C on which the object is placed; the focussing adjustment D D′, and the illuminating

FIG. 266.



The microscope.

shaft with mirrors E, diaphragms, condenser, and polarizer F, Fig. 266.

576. The Stage is for the support of the object. It is attached to the body in such a manner that the plane of its upper surface is at right angles to the optical axis of the tube.

In its simplest form, the stage is a single circular plate of brass with an aperture in the centre. Its upper surface is ground smooth and flat; on this the object slide is placed. By intervening a drop of water between the glass slide and the metal plate, the former is held in position, and yet may be easily and steadily moved on the metal, to bring any desired part of the object into the field of the instrument. As a rule, even the simplest stages are provided with clips, springs, or other contrivances for keeping the slide in contact while the former is moved about by the fingers.

In its more advanced condition it consists of two parallel plates, with more or less complex attachments for moving the upper upon the lower. The upper plate carries the object and slides upon the lower, which is firmly attached to the body of the instrument.

In the various forms of microscope a majority of the following movements of the object are attainable.

1st. *Right* or *left* across the field by turning one or the other of the mill-headed screws on the side of the stage, which drives the rack movement between the two plates of the stage.

2d. *Oblique* by turning both screw heads at the same time.

3d. *Rotary*, by loosening a binding-screw which holds the two parts of the stage together, when the upper may be rotated upon the lower by the finger or by a tangent screw.

4th. *Inclination* of the plane of the stage to the optical axis of the instrument. In this the lower plate is so attached to the body that by loosening a binding-screw, the movement in question may be executed.

5th. One or all of these may be provided with graduated scales, arcs, and verniers, that they can be measured, recorded, and restored if desired.

To secure the greatest obliquity in transmitted light, the stage should be made as thin as possible.

577. Focussing Apparatus.—This consists of appliances, D D′, which cause the tube to approach to or recede from the stage. In the simplest form the tube is supported in a metallic ring lined with cloth, and the movement in question is accomplished by sliding it up and down.

In the better forms of microscope, the arrangement described is sometimes retained as a coarse adjustment. As a rule, however, this is attained by a rack and pinion movement, the mill-heads of the latter being on each side the tube, while that which drives the lever of the fine adjustment is at the top of the body, where the lateral arm arises to support the main tube. In some cases the mill-head of the fine adjustment is on the tube.

In the low powers the coarse adjustment alone generally suffices to obtain a sharp focus. To give this the greatest smoothness the teeth of the rack and pinion should be set obliquely. "What is meant by '*spring*,' is the alteration which may often be observed to take place on the withdrawal of the hand; the object which has been brought precisely into focus, and which so remains while the milled head is between the fingers, becoming indistinct when the milled-head is let go. The source of this fault may lie either in the rack-movement or in the general framing of the instrument, which is so weak as to allow of displacement by the mere weight or pressure of the hand; should the latter be the case, the 'spring' may be in a great degree prevented by carefully abstaining from *bearing* on the milled-head, which should be simply *rotated* between the fingers."

To obtain a well-defined image with objectives of less than half an inch focus the fine adjustment or slow motion D′ must be used. "It should work smoothly and equably, producing that *graduated* alteration of the distance of the objective from the object which it is its special duty to effect without any jerking or irregularity. It should be so sensitive that any movement of the milled-head should at once make its action apparent by an alteration in the distinctness of the image when high powers are employed, without any loss of time. And its action should not give rise to any twisting or displacing movement of the image, which ought not to be in the least degree disturbed by any number of rotations of the milled-head, still less by a rotation through a few degrees. One great use of this adjustment consists in bringing into view different *strata* of the object, and this in such a gradual manner that their connection with one another shall be made apparent. A clearer idea of the nature of a doubtful structure is, in fact, often derived from what is caught sight of *in the act* of changing the focus, than by the most attentive study and comparison of the different views obtained by any number of separate 'focussings.' The experienced microscopist, therefore, whilst examining an object of almost any description, constantly keeps his finger upon the milled-head of the 'slow motion,' and watches the effect produced by its revolution upon every feature which he distinguishes; never leaving off until he is satisfied that he has scrutinized not only the entire *surface*, but the entire *thickness* of the object."

578. The Stand is generally some modification of a tripod, or three-footed arrangement. This, if properly constructed, gives the desired steadiness to the apparatus. In the earlier kinds

of microscope the body was immovably attached to the stand, and only a vertical view down the tube could be obtained. In modern instruments, the attachment between the body and stand is movable, and any desired obliquity can be given to the former. The microscopist is thus enabled to change his posture at pleasure, and the use of the instrument becomes less wearisome. Some think that an optical advantage is gained by using an inclined position of the tube, as there is less annoyance from the action of moisture upon the cornea.

579. Illumination may be by ordinary or by polarized light. In the former, the light is either transmitted or reflected, according as the object is transparent or opaque. In the first of these it may again be direct or oblique, and either simple or condensed. Five conditions, therefore, present themselves: 1st, simple axial; 2d, condensed axial; 3d, oblique; 4th, reflected; and, 5th, polarized illumination.

580. Simple Axial Illumination.—All microscopes are provided with a plane silvered glass mirror, or reflector, by which light can be directed through the aperture in the stage along the tube to the eye. In simple forms, this is supported upon an immovable rigid arm, which is attached to the body and projects beneath the stage. The mirror is mounted upon two axes at right angles to each other, that rays of light from any source may be directed along the tube.

581. Diaphragms.—For various reasons it is often necessary to modify or lessen the illumination. This is accomplished by means of a ring pierced by circular or other openings of different sizes. The *ring diaphragm* is generally attached to the under side of the main stage in such a manner, that on revolving it openings of various diameters are passed beneath the aperture in the centre of the main stage, and its size varied as desired. Thus a greater or less amount of light is thrown upon the object. Sometimes the diaphragm is placed at a distance below the object, as in the box form of this arrangement.

The *iris diaphragm* is a most ingenious piece of apparatus for varying the diameter of the pencil of light cast on the object. It is composed of a number of plates, which by means of a lever are made to encroach upon a central opening. It operates, as its name indicates, after the fashion of the iris, and gives most satisfactory results.

582. Condensed Axial Illumination.—To throw a brighter illumination upon the object, the light is condensed by any of the

three following methods: 1st, concave mirror; 2d, simple condensing lens; 3d, achromatic condenser.

Concave mirror. The ring, which carries the plane mirror, holds a concave one upon the opposite side, by which rays of light can be converged upon the object. To adjust the focus of this to near or remote sources of light, the ring slides upon the arm supporting it. It is thus made to approach, or recede from, the stage, and thereby bring the reflected rays to a focus upon the object.

Simple condenser is a convex lens of moderately long focus, intervened between the source of light and the plane mirror. The relative positions of these are so arranged that the light is brought to a focus upon the object. The lens is supported in a sliding ring upon an independent stand. It may, therefore, receive any desired adjustment.

Achromatic condensers. For condensing the illumination the lower objectives of the microscope may be used. Especial provision is made for mounting them by means of a second or sub-stage beneath the main stage of the instrument. The *sub-stage* is attached to the arm which carries the plane mirror. It is placed between that and the stage. By means of a rack and pinion movement, it traverses along the supporting arm, receiving the proper adjustment to cast the focus of the achromatic combination upon the object.

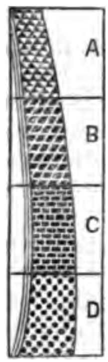
583. Oblique Illumination.—Where transparent objects present fine grooves or ridges, they are often invisible when submitted to axial illumination, but appear at once when the light is cast at the proper degree of obliquity upon them. According also as one side of a furrow is more or less inclined than the other, so will the direction in which the light falls make it more or less evident.

The simplest method of obtaining oblique illumination is to mount the arm supporting the mirror and sub-stage upon a pivot, the axis of which should pass through the plane of the object. The light may then be reflected upon it at any desired angle. If at the same time the movement of rotation is given to the stage, it will be presented to the light under every azimuth.

The *amici prism* is a prism one face of which is lens-shaped. It serves the purpose of a reflector and condenser in securing oblique illumination. It can be mounted on a separate stand, or attached to some part of the instrument.

The *parabolic illuminator* is a column of glass, the upper portion being paraboloid in shape with a cup or depression in the centre. By it the object may be illuminated obliquely,

FIG. 267.



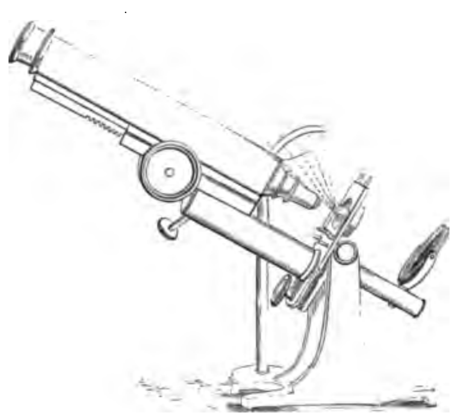
Varying effects of illumination.

and, if desired, made to appear on a black ground.

Regarding oblique illumination, Prof. Carpenter says: "A good example of the variety of appearances which the same object may exhibit, when illuminated from different azimuths, and with slight changes of focussing, is shown in Fig. 267, which represents portions of a valve of *pleurosigma formosum*, as seen under a power of 1300 diameters; the markings shown at A, B, and C, being brought out by oblique light in different directions, which, however, when carefully used, does not produce these erroneous aspects; whilst at D is shown the effect of axial illumination with the achromatic condenser. It cannot be too strongly impressed on the young microscopist, however, that the special value of *very oblique* illumination is limited to the resolution of 'test objects;' and that for ordinary purposes of *scientific* study, and research, *axial* illumination is generally preferable."

584. Reflected Illumination is employed with opaque objects. In this the light is thrown upon their upper surface and re-

FIG. 268.



Illumination of opaque objects.

flected thence along the shaft of the instrument. The simplest arrangement is found in Fig. 268. In this the rays from the source of light indicated by the dotted lines are condensed by a convex lens and brought to a focus upon the upper surface of

the object. A plano-convex lens of great curvature, called the *bull's-eye* condenser, is used for this purpose. It is mounted on a separate stand, and any desired movement can be given to it.

"The optical effect of such a bull's-eye differs according to the side of it turned towards the light, and the condition of the rays which fall upon it. The position of *least* spherical aberration is when its *convex* side is turned towards *parallel* or towards the *least diverging* rays; consequently, when used by daylight, its *plane* side should be turned towards the *object;* and the same position should be given to it when it is used for procuring converging rays from a lamp, this being placed four or five times further off on one side than the object is on the other. But it may also be employed for the purpose of reducing the diverging rays of the lamp to parallelism, for use either with a paraboloid or with the parabolic speculum; and the *plane* side is then to be turned towards the lamp, which must be placed at such a distance from the 'bull's-eye,' that the rays which have passed through the latter shall form a luminous circle equal to it in size, at whatever distance from the lens the screen may be held. For viewing minute objects under high powers, the smaller condensing lens may be used to obtain a further concentration of the rays already brought into convergence by the 'bull's-eye.'"

In some microscopes the arm which carries the plane mirror and achromatic condenser is not only turned to one side to give oblique illumination, as described in (583), but also above the stage to give reflected illumination, as with the bull's-eye condenser.

The *Lieberkühn* is a concave speculum, and received its name from the celebrated microscopist who invented it. "It is made to fit upon the end of the objective, having a perforation in its centre for the passage of the rays from the object to the lens; and in order that it may receive its light from a mirror beneath, the object must be so mounted as only to stop out the central portion of the rays reflected upwards. The curvature of the speculum is so adapted to the focus of the objective, that, when the latter is duly adjusted, the rays reflected up to it from the mirror shall be made to converge strongly upon the part of the object that is in focus; a separate speculum is consequently required for every objective."

The *parabolic speculum* of Mr. R. Beck is one of the most convenient methods for obtaining reflected illumination. "It is attached to a spring-clip that fits upon the objectives (2 inch, $1\frac{1}{2}$ inch, 1 inch, $\frac{2}{3}$d inch), to which it is especially suited, and is slid up or down, or turned around its axis, when the object has been brought into focus, until the most suitable illumination

has been obtained. The ordinary rays of diffused daylight, which may be considered as falling in a parallel direction on the speculum turned towards the window to receive them, are reflected upon a small object in its focus, so as to illuminate it sufficiently bright for most purposes: but a much stronger light may be concentrated on it when the speculum receives its rays from a lamp placed near the opposite side of the stage, a 'bull's eye' being interposed to give parallelism to the rays."

Vertical illumination through objective. Mr. Wenham, Prof. H. L. Smith, and others, have devised various methods for illuminating opaque objects by sending the light through the objective as a condenser. In the arrangement of Mr. Beck, a disk of thin glass is attached to a milled-head, by the rotation of which it may receive any desired angle; this is introduced through a slot into the interior of an adapter interposed between the objective and the nose of the microscope. The light which enters at the lateral aperture, falling upon the oblique surface of the disk, is reflected downwards, and concentrated by the lenses of the objective upon the object beneath.

585. Polarized Illumination.—In the application of polarized light to the microscope a bundle of thin plates may be used as the *polarizer*. The method usually employed is by a "Nicol" prism, fitted to the sub-stage. A second "Nicol" or tourmaline is used as an *analyzer*. It is placed near the objective. By means of polarized light important peculiarities of structure are made evident, which would otherwise be invisible.

586. Sources of Illumination.—1st. *Sunlight.* "The *direct* light of the sun is far too powerful to be ordinarily used with advantage, unless its intensity is moderated, either by reflection from a plaster-of-Paris mirror, or by passage through some 'modifier;' it is, however, occasionally used by some observers to work out intricate markings or fine color, and may sometimes be of advantage for these purposes, but without great care would be a fertile source of error."

2d. *Daylight.* "The young microscopist is earnestly recommended to make as much use of *daylight* as possible; not only because, in a large number of cases, the view of the object which it affords is more satisfactory than that which can be obtained by any kind of lamplight, but also because it is much less trying to the eyes. So great, indeed, is the difference between the two in this respect, that there are many who find themselves unable to carry on observations for any length of time by lamplight, although they experience neither fatigue nor strain from many hours continuous work by daylight."

3d. *Cloud light.* "When daylight is employed, the microscope should be placed near a window, whose aspect should be (as nearly as may be convenient) *opposite* to the side on which the sun is shining; for the light of the sun reflected from a bright cloud is that which the experienced microscopist will always prefer, the rays proceeding from a cloudless blue sky being by no means so well fitted for his purpose, and the dull lurid reflection of a dark cloud being the worst of all."

4th. *Lamplight.* "For the examination of the greater proportion of objects, *good daylight* is to be preferred to any other kind of light: but *good lamplight* is preferable to bad daylight, especially for the illumination of opaque objects. When recourse is had to artificial light, it is essential, not only that it should be of good quality, but that the arrangement for furnishing it should be suitable to the special wants of the microscopist." The most useful light for ordinary use is that furnished by the steady and constant flame of a flat-wicked lamp, fed with one of the best varieties of paraffin oil. For all ordinary purposes a flat kerosene flame used edgewise answers admirably.

5th. *Position of the light.* "When the microscope is used by daylight, it will usually be found most convenient to place it in such a manner that the light shall be at the left hand of the observer. It is most important that no light should enter his eye save that which comes to it through the microscope; and the access of direct light can scarcely be avoided when he sits with his face to the light. Of the two sides, it is more convenient to have the light on the *left;* first, because it is not interfered with by the right hand, when this is employed in giving the requisite direction to the mirror, or in adjusting the illuminating apparatus; and second, because, as most persons in using a monocular microscope employ the right eye rather than the left, the projection of the nose serves to cut off those lateral rays which, when the light comes from the right side, glance between the eye and the eye-piece. The lamp should always be placed on the left side, unless some special reason exists for placing it otherwise; and if the object under examination be *transparent*, the lamp should be placed at a distance from the eye about midway between that of the stage and that of the mirror; but when the instrument can be inclined, the lamp may be most advantageously placed in the axis of the achromatic condenser or other illuminator, so that its light may be transmitted to the object without intermediate reflection. If, on the other hand, the object be *opaque*, the lamp should be at a distance about midway behind the eye and the stage, that its light may fall on the object at an angle of about 45° with the axis of the microscope."

587. Augmentation of Magnifying Power.—"When the microscopist wishes to augment his magnifying power, he has a choice between the employment of an objective of shorter focus, and the use of a deeper eye-piece. If he possess a complete series of objectives, he will frequently find it best to substitute one of these for another without changing the eye-piece for a deeper one; but if his 'powers' be separated by wide intervals, he will be able to break the abruptness of the increase in amplification which they produce, by using each objective first with the shallower, and then with the deeper eye-piece. In the examination of large opaque objects having uneven surfaces, it is generally preferable to increase the power by the eye-piece rather than by the objective; thus a more satisfactory view of such objects may usually be obtained with a 3 inch or 2 inch objective, and the B eye-piece, than with a $1\frac{1}{2}$ inch or 1 inch objective, and the A eye-piece. The use of the draw-tube enables the microscopist still further to vary the magnifying power of his instrument, and thus to obtain almost any exact number of diameters he may desire, within the limits to which he is restricted by the focal length of his objectives."

588. Measurement of Magnifying Power.—For this purpose various forms of micrometer have been adapted to the eye-piece. The method generally employed "depends upon a comparison of the *real size* of the object with the *apparent size* of the image; but our estimate of the latter will depend upon the distance at which we assume it to be seen; since, if it be projected at different distances from the eye, it will present very different dimensions. Opticians generally, however, have agreed to consider *ten inches* as the standard of comparison; and when, therefore, an object is said to be magnified 100 diameters, it is meant that its visual image projected at ten inches from the eye (as when thrown down by the camera lucida (543) upon a surface at that distance beneath), has 100 times the actual dimensions of the object. The measurement of the magnifying power of simple or compound microscopes by this standard is attended with no difficulty. All that is required is a stage micrometer accurately divided to a small fraction of an inch (the $\frac{1}{100}$th will answer very well for low powers, the $\frac{1}{1000}$th for high), and a common foot rule divided to tenths of an inch. The micrometer being adjusted to the focus of the objective, the rule is held parallel with it at the distance of ten inches from the eye. If the second eye be then opened whilst the other is looking through the microscope, the circle of light included within the field of view crossed by the lines of the micrometer will be seen faintly projected upon the rule; and it will be very easy to mark upon the latter the apparent distances of the divisions on the

micrometer, and thence to ascertain the magnifying power. Thus, supposing each of the divisions of $\frac{1}{100}$th of an inch to correspond with $1\frac{1}{2}$ inch upon the rule, the linear magnifying power is 150 diameters; if it corresponds with half an inch, the magnifying power is 50 diameters."

589. Care of Microscope.—The best method for protecting a microscope when not in use is to keep it under a glass shade, the mouth closed by a piece of cloth laid on the table or stand on which it is kept. If there is any dust on the mirror or brass work it should be wiped off with a handkerchief before it is put away.

If specks are seen on looking through the eye-piece, when the mirror is adjusted to illuminate the field, the eye-piece should be rotated, when, if the dust is upon its glasses, they must be carefully wiped. In case it is necessary to remove the lenses from the barrel to wipe their inner surface, they should be screwed up taut when returned to their places. The lenses of only one eye-piece should be taken out at a time, to prevent any chance of their becoming mixed.

If the dust upon any lens is very fine, it can often be blown off. The vapor which condenses thereafter must be removed by quickly traversing the glass through the air. Lenses should not be wiped unless necessary, as the softest material is apt to injure or scratch the polish. If a puff of breath does not answer, the next best thing is a camel's-hair pencil, and, finally, a piece of soft wash-leather out of which the dust has been beaten.

If the objectives are kept in their cases, they will not often require the removal of dust. The chief danger to which they are liable is contact with fluids of various kinds when used by careless hands. When this happens they should be cleaned as quickly as possible.

Whenever objectives are handled, the glasses should be kept as far as possible from the vicinity of the skin, to prevent condensation of its moisture upon them. Any cloudiness that may appear in their interior is best treated by the maker, especially when it is between the parts of any of the achromatic lenses.

590. Care of the Eyes.—In regard to this matter we quote the experience of Prof. Carpenter: "Although most microscopists who habitually work with the monocular microscope acquire a habit of employing only *one* eye (generally the right), yet it will be decidedly advantageous to the beginner that he should learn to use either eye indifferently; since by employing and resting each alternately, he may work much longer without incurring

unpleasant or injurious fatigue, than when he always employs the same. Whether or not he do this, he will find it of great importance to acquire the habit of *keeping open the unemployed eye.* This, to such as are unaccustomed to it, seems at first very embarrassing, on account of the interference with the microscopic image which is occasioned by the picture of surrounding objects formed upon the retina of the second eye; but the habit of restricting the attention to that impression only which is received through the microscopic eye, may generally be soon acquired; and when it has once been formed, all difficulty ceases. Those who find it unusually difficult to acquire this habit, may do well to learn it in the first instance with the assistance of a shade; the employment of which will permit the second eye to be kept open without any confusion. So much advantage, however, is derived from the use of the binocular arrangement, either stereoscopic or non-stereoscopic, that its use is strongly recommended to every observer, save in cases of exceptional difficulty. There can be no doubt that the habitual use of the microscope, for many hours together, especially by lamp-light, and with high magnifying powers, has a great tendency to injure the sight. Every microscopist who thus occupies himself, therefore, will do well, as he values his eyes, not merely to adopt the various precautionary measures already specified, but rigorously to keep to the simple rule of *not continuing to observe any longer than he can do so without fatigue.*"

591. Errors of Interpretation.—"These, arising from the imperfection of the *focal adjustment*, are not at all uncommon amongst young microscopists. Indistinctness of outline will sometimes present the appearance of a pellucid border, which, like the diffraction-band, may be mistaken for actual substance. But the most common error is that produced by the reversal of the lights and shadows resulting from the refractive powers of the object itself; thus, the biconcavity of the blood-discs of human (and other mammalian) blood occasions their centres to appear *dark* when in the focus of a microscope, through the divergence of the rays which it occasions; but when brought a little within the focus by a slight approximation of the object-glass, the centres appear brighter than the peripheral parts of the discs."

"The student should be warned against supposing that, in all cases, the most *positive* and *striking* appearance is the truest; for this is often not the case. Mr. Slack's *optical illusion* or *silica-crack slide* illustrates an error of this description. A drop of water holding colloid silica in solution is allowed to evaporate on a glass slide, and, when quite dry, covered with thin glass to keep it clean. The silica deposited in this way is curiously

cracked; and the *finest* of these cracks can be made to present a very positive and deceptive appearance of being raised bodies like glass threads."

"A very important and very frequent source of error, which sometimes operates even on experienced microscopists, lies in the refractive influence exerted by certain peculiarities in the internal structure of objects upon the rays of light transmitted through them; this influence being of a nature to give rise to appearances in the image which suggest to the observer an idea of their cause that may be altogether different from the reality. Of this fallacy we have a 'pregnant instance' in the misinterpretation of the nature of the *lacunæ* and *canaliculi* of bone, which were long supposed to be solid corpuscles with radiating filaments of peculiar opacity, instead of being, as is now universally admitted, minute chambers with diverging passages excavated in the solid osseous substance. For, just as the convexity of its surface will cause a transparent cylinder to show a bright axial band, so will the concavity of the internal surfaces of the cavities or tubes hollowed out in the midst of highly refracting substances occasion a divergence of the rays passing through them, and consequently render them so dark that they are easily mistaken for opaque solids. That such is the case with the so-called 'bone corpuscles,' is shown by the effect of the infiltration of Canada balsam through the osseous substance; for when this fills up the excavations, being nearly of the same refractive power with the bone itself, it obliterates them altogether. The best method of learning to appreciate the class of appearances in question, is the comparison of the aspect of globules of oil in water with that of globules of water in oil, or of bubbles of air in water or Canada balsam. This comparison may be very readily made by shaking up some oil with water to which a little gum has been added, so as to form an emulsion; or by simply placing a drop of oil of turpentine (colored by magenta or carmine) and a drop of water together on a slip of glass, laying a thin glass cover upon them, and then moving the cover several times backwards and forwards upon the slide. Now when such a mixture is examined with a sufficiently high magnifying power, all the globules present nearly the same appearance, namely, dark margins with bright centres; but when the test of alteration of the focus is applied to them, the difference is at once revealed; for whilst the globules of oil surrounded by water become *darker* as the object-glass is *depressed*, and *lighter* as it is *raised*, those of water surrounded by oil become *more luminous* as the object-glass is *depressed*, and *darker* as it is *raised*. The reason of this lies in the fact that the high refracting power of the oil causes each of its globules to act like a double-*convex* lens of very short focus; and as this

will bring the rays which pass through it into convergence *above* the globule (*i. e.*, between the globule and the objective), its brightest image is given when the object-glass is removed somewhat further from it than the exact focal distance of the object. On the other hand, the globule of water in oil, or the minute bubble of air in water or balsam, acts, in virtue of its inferior refractive power, like a double-*concave* lens; and as the rays of this diverge from a virtual focus *below* the globule (*i. e.*, between the globule and the mirror), the spot of greatest luminosity will be found by causing the object-glass to approach *within* the proper focus. A thorough mastery of these appearances is very important in the study of the 'protoplasm' of plants—the 'sarcode' of animals,—which includes oil-particles, together with spaces occupied by a watery fluid, which (having been at one time supposed to be *void*) are known as '*vacuoles.*'"

592. Non-vital Motions.—The power of self-movement is generally given as the leading attribute of living creatures, but it is now known that all substances, organic and inorganic, will exhibit a kind of motion known as *pedesis*, if reduced to the proper degree of subdivision and suspended in a fluid. When the specific gravity of the liquid approximates closely to that of the particles of the solid a less degree of subdivision is required.

This "*Brownian movement*," as it is also called, is oscillatory, the particles rotating backwards and forwards upon their axes, and changing their position slightly in the field of view. Among the substances that show it to good advantage are the fine kaolin prepared for photographers, when suspended in water, or very finely divided pumice. In examination of urine, minute crystals of certain phosphates exhibit this motion, which must not be confounded with that of bacteria and like organisms.

593. Binocular and Chemical Microscopes.—In the former the pencil of light from the objective is divided by a prism and passed along two shafts, each terminating in an eye-piece. By this device great advantages are gained over monocular instruments, in certain special investigations, especially in those binoculars arranged to produce stereoscopic effects.

The *chemical microscope* differs from an ordinary instrument in that the shaft is placed below instead of above the stage. The object may, therefore, be examined by acids and other reagents without injury to the objective, as it is protected by the glass slide on which the substance has been placed.

For further information regarding these and all other matters concerning microscopes, the student is referred to Prof. Car-

penter's work on the "Microscope," from which this Chapter has been so largely quoted, and of which we cannot speak too highly.

593 A. Fixation of Images may be accomplished either by the hand and pencil with the aid of the camera lucida, or by means of photography. In the former the method is identical with that described for the measurement of magnifying power in (588). An improved camera lucida by Zeiss will be found to offer increased facilities for this operation.

Where the photographic method is employed, an ordinary camera box, from which the lenses have been removed, is substituted for the eye-piece of the microscope. The two instruments may be connected light-tight by means of black velvet or cloth, and the image focussed on the ground glass of the camera. A beam of sunlight rendered stationary by a heliostat, and condensed if necessary, is the best method of illumination for high powers. To make the chemical and visual foci the same, and thereby avoid all difficulty in obtaining sharply defined pictures, the beam should be passed through a glass cell filled with ammonio-sulphate of copper, which allows only violet and blue light to pass freely. Prof. J. W. Draper employed this method to obtain photographs for his work on "Physiology," and was the first to make photographs by the high powers of the microscope.

594. Preparation of Slides and Covers.—For the support of the object under the objective, *glass slides* are required. These are made of a patent plate manufactured for the purpose. It should be free from air-bubbles, veins, or other imperfections, and cut to a size of three inches by one, with the edges ground. They may be purchased for about the same cost as the glass itself, and sorted according to thickness into groups for different purposes. The *thinnest* should be used for investigations requiring high power, the *medium* for ordinary objects, and the *thick* for those which are to be ground down.

To *cleanse the slides*, immerse them for twenty-four hours in strong sulphuric acid; then rinse in potash or soda solution, followed by distilled water; then wipe dry with a towel, and polish with an old handkerchief. Another method is to immerse them for a day in a fluid composed of—

Potassium dichromate	2 oz.
Sulphuric acid	3 fl. oz.
Water	25 fl. oz.

Before a slide is used, the dust should be carefully wiped off.

Old slides should have the varnish removed by scraping, then by a suitable solvent adapted to the nature of the varnish, then rubbed with a fluid composed of equal parts of benzole, alcohol, and *liquor sodæ*, and finally washed in clean water.

The *thin glass* required for covering and protecting the object may be purchased already cut in squares and circles. Pieces as thin as $\frac{1}{550}$ of an inch can be obtained. It is very brittle; and if required of special size, must be laid on a piece of wet plate glass, to prevent cracking, and cut with a writing-diamond.

It should be sorted into three grades, the thickest for low, the medium and thinnest for high powers.

For injected specimens, and thick objects requiring space between the slide and cover, cells are constructed either with rings of cement, glass, or rubber, prepared for the purpose. These cements are also used for sealing the cells when the mounting is completed.

Large, deep cells are built up of carefully ground pieces of plate glass.

595. Preparation of Object.—The specimen examined may be either transparent or opaque, fluid or solid. The simplest case is a *fluid containing free cells* or corpuscles—as, for example, blood. In this instance, a drop is transferred to the centre of the slide by a glass rod, the cover is then gently laid on in such a manner that it touches along one side first; the entrapping of air-bubbles is thus avoided. The margin of the cover is then touched with a piece of blotting-paper, which absorbs the excess of fluid by capillary attraction, and the specimen is ready for examination.

If a *sediment* is to be examined, it may be transferred without additional mixture with fluid, by the use of a pipette (186); it is then covered, and excess of fluid removed, as in the preceding case.

Soft solids, especially if fibrous, are prepared by taking a thin slice and teasing the fibres apart by *needles*. For this purpose, ordinary sewing needles can be fitted into wooden handles by the eye extremity. The free end is straight, or curved as required. To obtain the latter, raise the temperature of the free end for a moment to red heat: when cool, bend as desired. It is then again made red-hot, and while in that state immersed in cold water, to restore hardness.

596. Hardening and Section-cutting.—In a great number of cases it is necessary to harden animal substances before they can be cut into thin sections for examination. In many of the lower creatures the proportion of water is so great that its removal involves a shrinkage which completely obscures their structure. The following are the chief agents employed:

Alcohol: The material should be first soaked for a day or so in a mixture of equal parts of rectified spirit and water, then for a couple of days in rectified spirit, and then in absolute alcohol. The opacity arising from coagulation of the albuminous constituents is avoided by the addition of a little caustic soda.

Chromic acid is very generally employed. It should be kept in one per cent. solution, and diluted when used. Carpenter recommends the following mode of procedure:

"The menstruum having been prepared by mixing two parts of a one-sixth per cent. solution of chromic acid and one part of methylated spirit, the material must be cut into pieces about half an inch square, and put into a wide-mouthed stoppered bottle holding from six to ten ounces of the fluid; this fluid should be changed at the end of twenty-four hours, and then every third day. The material will be sufficiently hard in from eight to twelve days. If not, the process must be continued, care being taken that it be not so prolonged as to render the substance brittle. The hardening may afterwards be completed by transferring the substance first to dilute and then to stronger spirit. The spirit must be changed as often as it becomes foul; when it remains bright and clean, the specimen is ready for cutting."

Osmic acid: "This agent is one of peculiar value to the microscopist whose studies lie among the lower forms of animal and vegetable life, as its application immediately kills them, without producing any retraction or shrinking of their parts, and not only preserves their tissues, but brings out differences in those which might otherwise escape observation. It is sold in the solid state in sealed tubes, and is most conveniently kept as a one per cent. solution in distilled water. The solution should be preserved in well-stoppered bottles secluded from the light, and should be used with great caution, as it gives forth a pungent vapor which is very irritating to the eyes and nostrils. To the histologist, its special value lies in its blackening of fatty matters and the medullary substance of nerve-fibres. The embryologist finds it of peculiar value in giving firmness and distinctness to the delicate textures with which he has to deal. Various degrees

of dilution of the one per cent. solution will be needed for these different purposes. Mr. Parker states that he has found this agent very serviceable in the preparation of delicate vegetable structures. The acid seems to be taken up by each granule of the protoplasm, and these to be decomposed, giving to the granule the characteristic gray color, thus at the same time both hardening and staining. A mixture of nine parts of a one-fourth per cent. solution of chromic acid, with one part of a one per cent. solution of osmic acid, answers for many purposes better than osmic acid alone, the brittleness produced by its use being completely avoided. After being subjected to this agent, the specimens should be treated with thirty per cent. alcohol, gradually increased in strength to absolute."

For cutting *thin sections*, various devices are employed. The simplest is that by small, keen-bladed *scissors*, which are either straight or curved. The best are provided with a spring, by the action of which the blades are self-opening. For finer work, and to secure parallel surfaces, Valentine's two-bladed knife was formerly used, but it has been superseded by better methods, among which is the—

597. Simple Microtome, which is described as follows by Prof. Carpenter: "Various costly machines have been devised for this purpose, some of them characterized by great ingenuity of contrivance and beauty of workmanship; but most of the purposes to which these are adapted will be found to be answered by a very simple and inexpensive little instrument, which may either be held in the hand, or (as is preferable) may be firmly attached by means of a **T**-shaped piece of wood, Fig. 269, to the end of a table or work-bench. This instrument consists essen-

FIG. 269.

Microtome.

tially of an upright hollow cylinder of brass, A, with a kind of piston which is pushed from below upwards by a fine-threaded or 'micrometer' screw turned by a large milled-head, B; at the upper end the cylinder terminates in a brass table, C, which is planed to a flat surface, or (which is preferable) has a piece of plate glass cemented to it, to form its cutting-bed. At one side is seen a small milled-head, D, which acts upon a 'binding-screw,' whose extremity projects into the cavity of the cylinder, and serves to compress and steady anything that it holds. A cylindrical stem of wood, a piece of horn, whalebone, cartilage, etc., is to be fitted to the interior of the cylinder so as to project a little above its top, and is to be steadied by the 'binding-screw;' it is then to be cut to a level by means of a sharp knife or razor laid flat upon the table. The large milled-head is next to be moved through such a portion of a turn as may very slightly elevate the substance to be cut, so as to make it project in an almost insensible degree above the table, and this projecting part is to be sliced off with a knife previously dipped in water. For many purposes, an ordinary razor will answer sufficiently well, but thinner and more uniform sections can be cut by a special knife, having its

edge parallel to its back, its sides slightly concave, and its back with a uniform thickness of rather less than one-fourth inch. Such a knife should be four or five inches long, and seven-eighths inch broad; and should be set in a handle about four inches long. The motion given to its edge should be a combination of *drawing* and *pressing*. It will be generally found that better sections are made by working the knife *from* the operator than *towards* him. When one slice has been thus taken off, it should be removed from the blade by dipping it into water, or by the use of a camel's-hair brush; the milled-head should be again advanced, and another section taken; and so on. Different substances will be found both to *bear* and to *require* different degrees of thickness; and the amount that suits each can only be found by trial. It is advantageous to have the large milled-head graduated, and furnished with a fixed index, so that this amount having been once determined, the screw shall be so turned as to produce always the exact elevation required. Where the substance of which it is desired to obtain sections by this instrument is of too small a size or of too soft a texture to be held firmly in the manner just described, it may be placed between the two vertical halves of a cork of suitable size to be pressed into the cylinder; and the cork, with the object it grasps, is then to be sliced in the manner already described, the small section of the latter being carefully taken off the knife, or floated away from it, on each occasion, to prevent it from being lost among the lamellæ of cork which are removed at the same time. Vertical sections of many leaves may be successfully made in this way."

In Hailes's microtome the irregular action of the raising screw is corrected by the use of two cylinders, one working inside the other.

When the substance is very soft, it is embedded in a cylinder of elder-pith, cut to fit the cylinder of the microtome. Plugs of paraffine, made by pouring the melted material into the cylinder of the microtome, are also employed. The substance is set in the plug, which is then inserted into the microtome cylinder. To give greater consistency to the embedding material, especially where fats are used, various forms of freezing microtome have been devised. These are essential in the preparation of sections of such tissues as lung, where the fat must be sufficiently soft to penetrate the interstices of the body to be embedded, and afterwards gain sufficient consistency to support the tissue before the edge of the knife.

Thin sections of hard tissues, like bone, are prepared by grinding them down after attaching them to glass.

598. Injection.—Injections should be opaque where inequalities of form are to be shown, and transparent where the vessels of thin transparent membranes are to be displayed. The material generally used is fine *size* or *gelatine* of the consistence of a firm jelly when cold. The solution should be strained through new flannel while hot, and preserved from dust under a layer of alcohol in a covered jar.

The best red coloring matter is levigated vermilion, about two ounces to the pint of size, thoroughly mixed therewith while melted, and the mixture strained through muslin.

For a yellow, freshly precipitated chromate of lead may be employed. It should be prepared as follows: Dissolve 200 grains of plumbic acetate, in another portion of water 105 grains of potassium chromate, mix, stir, allow precipitate to settle; decant the fluid from the sediment, and mingle the latter with four ounces of size.

An elegant method of injecting consists in throwing first one and then the other of these solutions into the vessels. For this purpose, the solutions should be saturated. In this case the nitrate of lead answers better than the acetate.

For white injections, carbonate of lead is recommended.

Blue injections do not answer well; they appear black.

The syringe should be fitted with jet pipes of various sizes, or glass jets may be drawn down to fit the vessels accurately. Since delicate vessels are often easily cut by thread, the jets should be used without ligatures, as large a jet as possible being employed. The pressure upon the piston of the syringe should be moderate and steady. In place of a syringe, a vessel filled with the injection, and attached to a jet by a long rubber tube, may be used; by raising the vessel to different heights any desired amount of uniform pressure may be obtained, or it may be gradually increased.

When the injection is not made into the vessels of the living creature, it should be performed either at once after death, or when the *rigor mortis* has passed off.

All vessels by which the injection might escape should be tied, and if too minute for this, the tissues themselves must be ligatured.

599. Staining acts either by simply dyeing, or by chemically uniting with some of the organic constituents of the preparation, and thus differentiates them from others. The agents which dye the structures are chiefly animal or vegetable coloring matters; it is generally necessary to fix these by means of some "mordant." Those which *act chemically* are mineral bodies.

Staining is sometimes done before the section-cutting, sometimes afterwards. The latter method is to be followed when the tissue has been hardened by the use of chromic acid. If the staining is to be *en masse*, the fluid should be weak and its action slow. In the case of thin sections, it should be conducted as rapidly as possible, and stopped at the right stage. Generally, watch-glasses or small capsules can be used for section-work, but when the laminæ are very thin, the operation may be conducted on the microscope-slide on which the preparation is to be mounted. In this case the fluid is added and removed by means of a small syringe. Sometimes it is carried on even after the thin glass cover has been put on.

Many different agents have already been successfully applied for this purpose, but the field is yet an extensive one and open to great improvement, although important results have been attained. Among the substances which have thus far been utilized, the following deserve especial mention:

Carmine was one of the first used. It was introduced by Dr. Beale for distinguishing protoplasm from other formed material. It has an especial affinity for cell nuclei. It is prepared as follows:

Carmine	10 grs.
Liquor ammoniæ	fʒss.

Warm in a test-tube, and boil for a few seconds, cool, add—

Aq. dest.	
Glycerine	āā ℥ij.
Alcohol	℥ss.

After a while, filter. If, in time, the carmine deposits, add a drop or so of ammonia.

To fix the carmine stain, immerse the section in dilute acetic acid, five drops to one ounce of water.

Picro-carmine, diluted and used alone, gives a double-staining action, nuclei attracting the carmine, and the other tissues the picric acid. In water the picric acid is removed, and the carmine stain remains. In methylated spirit both colors are retained.

Hæmatoxylin, or extract of logwood, is commonly employed in place of carmine. It is used as follows:

Extract of logwood	6 grammes.
Alum	18 "
Water	28 cub. cent.

Filter, and add ʒj of alcohol; preserve in stoppered bottle for a week before use. Ten drops diluted with water in a watch-glass may be used for each section. The color should be fixed with methylated spirit. The acetic acid mixture used to fix the carmine stain, will remove excess of hæmatoxylin stain.

Magenta acts like carmine, but is apt to fade.

Magenta crystals	grs. 1½.
Aq. dest.	f℥vij.
Alcohol	℥ss.

Eosin gives a beautiful garnet-red color.

Aniline dyes for blue and green colors.

Argentic nitrate and *Auric chloride* are sometimes employed; the former for epithelium cells, the latter for nerve, tendon, and cartilage cells.

Valuable information may often be obtained by the use of two or three staining-fluids, each of which will be fixed by different tissues. If, for example, a section is made through the base of a cat's tongue, and submitted to the action of a mixture of picro-carmine, rosein, and iodine-green, the muscle-fibres will take the first; the connective tissue and protoplasm cells, the second; the non-striated muscle, epithelial cells, the third. The effects are more striking if one fluid is used after another.

600. Chemical Testing is best accomplished by means of a small glass syringe, upon the slide on which the object is to be mounted. For examination of inorganic bodies all kinds of reagents may be used, but in biological investigations the following are of especial importance:

Lugol's solution turns starch blue, cellulose brown, and albuminous bodies an intense brown.

Nitric acid, concentrated, gives intense yellow to albuminoids.

Millon's reagent, acid nitrate of mercury, gives a red with albuminoids.

Acetic acid acts upon certain tissues, so that nuclei are made more apparent.

Fixed alkalies, in solution, act as solvents on many tissues; the cells of horny structures may thus be made evident.

Ether dissolves resin, fats, and oils, when not protected by membranes soaked with water.

Alcohol dissolves resins and some volatile oils, but not the ordinary oils and fats. It coagulates albuminoids, thus rendering such tissues more opaque.

601. Preservative Media.—Regarding these, Prof. Carpenter says:

"A broad distinction may be in the first place laid down between *resinous* and *aqueous* preservative media; to the former belong only Canada balsam and dammar, whilst the latter include all the mixtures of which water is a component. The choice between the two kinds of media will partly depend upon the nature of the processes to which the object may have been previously subjected, and partly upon the degree of transparence which may be advantageously imparted to it. Sections of substances which have been not only embedded in, but penetrated by, paraffine, wax, or cacao-butter, and have been stained (if desired) previously to cutting, are, as a rule, most conveniently mounted in Canada balsam or dammar, since they can be at once transferred to either of these from the menstruum by which the embedding material has been dissolved out. The durability of this method of mounting makes it preferable in all cases to which it is suitable; the exception being where it renders a very thin section *too* transparent, which is specially liable to happen with dammar. When it is desired to mount in either of these media sections of structures that have been embedded in gum or gelatine, these substances must first be completely dissolved-out by steeping in water; the sections must then be 'dehydrated' by subjecting them to mixtures of spirit and water progressively increased in strength to absolute alcohol; and, after this has been effected, they are to be transferred to turpentine, and thence to benzole. In this process much of the staining is apt to be lost, so that stained sections are often more advantageously mounted in some of those aqueous preparations of glycerine which approach the resinous media in transparence and permanence."

Among the aqueous media, the following have especial consideration:

Distilled water, saturated with camphor, for minute protophytes. The addition of one-tenth part of alcohol is of advantage when the preservation of color is not desired.

Carbolic acid solution, made with cold distilled water.

Salicylic acid solution, in water, for delicate structures.

Glycerine, either alone, diluted, or mixed with gelatinous substances. "Two cautions should be given in regard to the employment of glycerine: *first*, that, as it has a solvent power for carbonate of lime, it should not be used for mounting any object having a calcareous skeleton; and, *second*, that in proportion as it increases the transparence of organic substances, it diminishes the reflecting power of their surfaces, and should never be employed, therefore, in the mounting of

objects to be viewed by *reflected* light, although many objects mounted in the media to be presently specified are beautifully shown by 'black-ground' illumination."

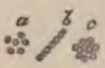
Glycerine jelly, subject to the same cautions. It may be prepared as follows: "Take any quantity of Nelson's gelatine, and let it soak for two or three hours in cold water; pour off the superfluous water, and heat the soaked gelatine until melted. To each fluidounce of the gelatine add one drachm of alcohol, and mix well; then add a fluid-drachm of the white of an egg. Mix well while the gelatine is fluid, but cool. Now boil until the albumen coagulates, and the gelatine is quite clear. Filter through fine flannel, and to each fluidounce of the clarified gelatine add six fluid-drachms of Price's pure glycerine, and mix well. For the six fluid-drachms of glycerine, a mixture of two parts of glycerine to four of camphor-water may be substituted. The objects intended to be mounted in this medium are best prepared by being immersed for some time in a mixture of one part of glycerine with one part of diluted alcohol (one of alcohol to six of water). A small quantity of carbolic acid may be added to it with advantage. When used, the jelly must be liquefied by gentle warmth, and it is useful to warm both the slide and the cover-glass previously to mounting. This takes the place of what was formerly known as Deane's medium, in which honey was used to prevent the hardening of the gelatine."

601 A. The Microscope and Disease Germs.—We have given the details of the processes of staining, section-cutting, etc., to enable the student to understand the methods resorted to of late in the study of the relations of certain plant-germs to various diseases. That the importance of this subject may be appreciated, we give a list of the specimens exhibited at the Biological Laboratory of the Health Exhibition at London, during the summer of 1884, preceding it with a brief account of the organisms themselves.

They are known as *Schizomycetes*. They resemble *algæ*, in that they live in water; and plants, in that they can feed upon ammonia for their nitrogenized material, but they cannot decompose carbonic acid. Their carbon food is derived from carbohydrates. The following five well-defined groups are recognized:

1. *Micrococci.* Dark-colored spherical or oval minute cells. Sometimes spores of bacteria, or bacilli, but as they often do

FIG. 270.

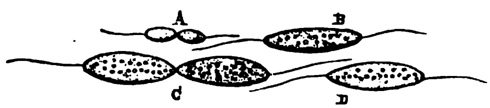


Micrococci.

not develop into anything higher than micrococci, must be regarded as a special form.

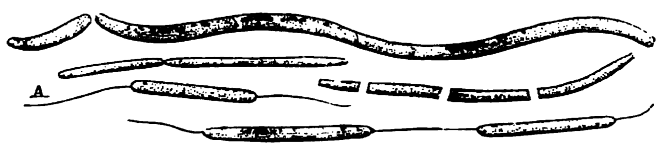
2. *Bacteria.* Minute oblong cells, usually attached in pairs end to end, are sometimes single, reproduce by fission, usually in vacillating movement by their *flagella.* Flagella frequently $\frac{1}{200000}$th inch thick, in special ferments, as that of sour milk.

FIG. 271.



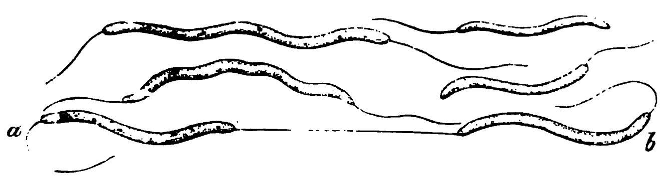
A. Bacterium termo, 4000 diameters. B, C, D. Bacterium lineola, 3000 diameters.

FIG. 272.



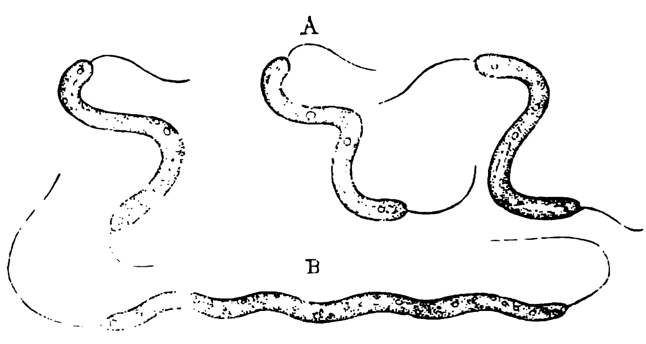
A. Bacillus subtilis, 4000 diameters.

FIG. 273.



Vibrio regula, 2000 diameters.

FIG. 274.



A. Spirillum undula, 3000 diameters; B. Spirillum volutans, 2000 diameters.

3. *Bacilli.* Special character, extension of its cells into straight rods, sometimes very long, which divide transversely into separate cells with flagellum at each end. Move in a pausing manner, like a fish forcing its way through reeds. B. anthracis, $\frac{1}{2000}$th to $\frac{1}{10000}$th inch long. Multiply idefinitely in tissues.

4. *Vibriones* resemble bacilli, but are flexible instead of straight. Formed chiefly in infusions of decomposing organic matter; have a wavy, serpentine movement.

5. *Spirilla* are the largest of the group. Have the cell spirally coiled, and possess a corkscrew-like movement; found in stale liquids which have passed through the active stage of putrescence.

All these multiply either by transverse cell subdivision, or by the breaking up of their endoplasm into spores, the reproduction of which is entirely non-sexual.

Most of the specimens in the Biological Laboratory were cultivated in an infusion made as follows:

Lean meat	1 pound.
Gelatine	100 grammes.
Peptone	10 "
Sodium chloride	1 "
Water, distilled	1 litre.

The solution is boiled and kept in separate flasks plugged with cotton. The mouth of the tube is also protected from contact with air.

The infusion, when cold, sets as a jelly, and in it the growths take place. Sometimes they liquefy it. In all cases the greatest care should be taken to sterilize the infusion by heating it one hour in the tube in which the experiment is to be performed, at 100° C., keeping the tube plugged with cotton.

A single drop of London water drawn from the tap into a test-tube containing two inches of this infusion, quickly liquefied, and produced a copious deposit.

Violet and fluorescent bacilli were exhibited; also bacilli from green and blue pus, and from blue milk.

Bacilli of tubercle, found in all tubercular and scrofulous diseases of joints, bones, glands, and in phthisis, were best cultivated in sterilized blood serum, maintained at the temperature of the body. According to Dr. Koch, inhalation of, or inoculation by, these germs, produces tuberculosis in the lower animals.

Bacilli of enteric fever, obtained from sections of intestinal ulcers, found also in the spleen, liver, and in the kidney, in colonies in the bloodvessels. Cultivated in meat solution.

Bacilli of anthrax, occurring as wool-sorters' disease, and malignant carbuncle. Found in blood and in heart tissue. They are the largest of bacilli. Cultivated in meat solution produce spores, but not in the body. Inoculation in lower animals,

according to Dr. Koch, causes rapid development of the disease and death in a few hours, the blood being filled with the characteristic bacilli.

Bacilli of mouse septicæmia, found in decomposing fluids, are very small, produce haziness along track of needle in meat solution. Mice inoculated die in 40 to 72 hours, bacilli in the blood and in white corpuscles. Inoculated in ear of rabbit, causing swelling and redness extending to other ear. Disappears in 5 or 6 days, leaving the animal protected for a time against the disease, a point worthy of special attention.

Bacilli of chicken cholera produce hemorrhagic enteritis of duodenum. Are very minute and stained at ends. Fowls and pigeons inoculated die in 17 to 20 hours with great number of bacilli in the blood.

Micrococci of acute osteomyelitis in man occur in the pus, may be cultivated in meat solution or in blood serum. Introduced into rabbit's veins, if the bones have been injured, cause death on the 12th day, the condition of the bones being the same as in man in this disease. Is found in the pus and blood in colonies.

Micrococci of acute lobar pneumonia. Found in blood, sections of affected parts and their exudations, especially in death in the acute stage. Grow rapidly in meat solution, particularly at points of entrance of needle, hence called nail-like. No capsule in cultivated kinds, but developed in creatures inoculated with the cultivated material. Inhaled by mice cause pneumonia. Injected into pleural cavity give pleurisy and pneumonia. Dogs, guinea-pigs, mice affected; rabbits not.

Micrococci of erysipelas in man. Found in lymphatic vessels at spreading margin of the redness, many tubes being completely blocked with these organisms. Grow in chains; cultivated in meat solution. This inoculated in ear of rabbit produces disease like erysipelas in man, with same condition of lymphatics. In man lupus, rodent ulcers, and cancerous tumors have been supposed to be influenced favorably by cultivated erysipelas inoculation. (Dr. Febreisen, Berlin, 1883.)

Micrococcus Tetragenus. Found in phthisical sputa where destruction of lung is rapid. Unstained, resembles sarcina; stained the groups are made up in fours. Inoculated in mice and guinea-pigs, they die in 2 to 10 days. The 4 groups found in capillaries of all the organs, large masses of these accumulating in the spleen burst through its peritoneal coat and cause peritonitis.

In addition to these cultivated specimens, photographs of the following were exhibited. The power best adapted was 700 diameters.

Nos. 1, 2, 3. Pyæmia in rabbits, micrococci.

Nos. 4, 5, 7, 8, 9. Erysipelas in man, micrococci.

Nos. 10, 13. Osteomyelitis, micrococci.

No. 11. Diphtheritic inflammation of bladder in man, plugs of micrococci in kidney vessels.

Nos. 14, 15. Progressive formation of abscess in rabbits, micrococci.

No. 16. Recurrent fever in monkey. Spirilla among blood corpuscles.

No. 18. Ditto in man, similar spirilla.

Nos. 19, 22, 23. Smallpox in man. Liver section plugged with micrococci.

Nos. 20, 21. Pyelonephritis. Microörganisms in tubules.

No. 25. Erysipelatous process in rabbits. Long delicate bacilli penetrating the tissues.

Nos. 26, 27. Ulcerative endocarditis. Heart section. Plugs of micrococci in capillaries.

Nos. 28, 32. Septicæmia in rabbits. Small intestine section. Capillary plugged with oval micrococci. Same in glomerulus of kidney.

Nos. 30, 31. Septicæmia in mice, blood, and section of ear showing minute bacilli.

Nos. 33, 34. Splenic fever in rabbits. Section of kidney, bacilli.

Nos. 35, 36. Glomerulus with anthrax bacilli. Same in sections of villus and of liver.

602. Telescopes.—According as these depend upon concave mirrors, or convex lenses, for their action, they are called *catoptric* and *dioptric* instruments. In the first the pencil of light reflected from the concave mirror is passed through an eye-piece to the eye. In the second, the objective or lens is a convex-achromatic of long focus, and considerable diameter, from this the rays are also passed through an eye-piece. The latter is generally of the form described in (573). When a telescope is intended for use on land, or for objects at a moderate distance, it is called *terrestrial;* when for contemplation of objects in the heavens, *celestial.* In the former the eye-piece is so modified as to present an erect image. In instruments for observation, or reading scales, and for other purposes, as the spectroscope, this form is commonly employed.

The *opera-glass* is constructed upon the principle of Galileo's telescope, which is the simplest. It consists of two lenses only, viz., a double-convex as the objective, and a double-concave as the eye-piece. Thus a very bright erect image is produced.

CHAPTER XXVII.

DOUBLE REFRACTION, INTERFERENCE, DIFFRACTION, AND POLARIZATION.

Double refraction—Ordinary and extraordinary ray—Interference of light—Diffraction—Diffraction spectra—Plane polarization by reflection—Angle of polarization—Polarization by single refraction—Polarization by double refraction—Polarizing instruments—Theory of polarized light—Interference of polarized light—Depolarization—Action of thin films—Production of colored rings by polarized light—Detection of molecular change by polarized light—Elliptical and circular polarization—Theory of elliptical and circular polarization—Production of circularly polarized light—Production of elliptically polarized light—Production and theory of rotatory polarization—Coloration by rotatory polarization—Rotatory power of liquids—Saccharimeter.

THESE are additional phenomena presented by light under special conditions, and produced by action of surfaces and media. They are all explicable upon the wave or undulatory hypothesis, and afford most satisfactory evidence of its correctness. To the physiologist and student of medicine they are of interest, either from their direct application in explaining the phenomena he witnesses, or in furnishing the principles upon which certain instruments are constructed which are used in determining the changes resulting from morbid actions in the system.

603. Double Refraction.—If a crystal of Iceland spar be placed upon a sheet of paper which bears a dark spot or dot, the latter

FIG. 275.

Double refraction.

appears double when viewed through the crystal. To this phenomenon of splitting or bifurcation of the pencil of light in its

sage, the name of double refraction has been given. All stals which do not belong to the cubical system, show this perty to a greater or less extent; Iceland spar being at the d of the list. Non crystalline substances, like glass, in their inary state are not double refracting, though they may be de to assume that property by unequal compression, or when nnealed.

f any double refracting crystal is carefully examined, it will found that there is one direction or axis in which the spot is doubled. This is called the *optic axis*. In some two such s are found. The first is called *uniaxial*, the second *biaxial*.

04. Ordinary and Extraordinary Ray.—If in the experiment ated in the preceding article, the line of vision is perpen- ular, and the crystal turned around with its face in continu- contact with the paper, that image of the dot nearest to the e of vision will remain unchanged, while the other will re- ve around it. The first of these is called the *ordinary*, the ond the *extraordinary* ray, or image. The former follows the s of single refraction, viz., the sines of the angles of inci- ice and refraction bear a constant relation to each other, and planes of incidence and refraction are coincident (492). The ter, on the contrary, follows neither of these laws except in tain positions.

According as the refractive indices of the ordinary and extra- linary rays of uniaxial crystals bear certain relations to each ier, they are called negative and positive. If the ordinary lex is greater than the extraordinary, it is called negative, d *vice versâ*.

Negative uniaxial crystals.

Iceland spar.	Ruby.	Pyromorphite.
Tourmaline.	Emerald.	Ferrocyanide of potassium.
Sapphire.	Apatite.	Nitrate of sodium.

Positive uniaxial crystals.

Zircon.	Apophyllite.	Titanite.
Quartz.	Ice.	Boracite.

Biaxial crystals.

Nitre.	Sugar.	Sulphate of iron.
Strontianite.	Selenite.	Mica.
Arragonite.	Anhydrite.	Epidote.
	Heavy spar.	

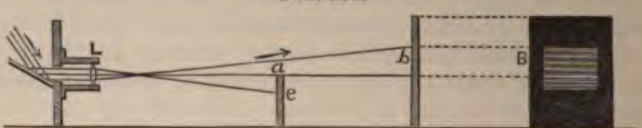
805. Interference of Light.—Make two small apertures of the ne diameter, and close to each other, in the shutter of a dark om; cover them with a sheet of red glass, two conical pencils

of red light will be formed, which meet and overlap each other at a certain distance from the shutter. If a screen is introduced into their path beyond this position, it will be seen that the overlapping segment produces an image composed of alternate red and black bands. On shutting out the light from either aperture, the dark bands at once disappear. It is, therefore, evident, that the dark fringes have been caused by the interference of the two pencils when they have crossed, and that, as with sound, two systems of waves may interfere and destroy each other, producing silence; so with light, two systems interfere and produce darkness.

The same results are obtained with any other homogeneous light, the only difference being in the distances of the bands from each other. This experiment is regarded as giving the most satisfactory evidence of the correctness of the undulatory or wave hypothesis of light. In white light the component colors produce dark bands at different intervals, these being superimposed but not coincident; the dark lines of one color are illuminated by the others, and a series of colored bands arise.

606. Diffraction.—If a beam of sunlight is admitted through one of the apertures, and the pencil of red light passed through a short-focus convex lens, L, Fig. 276; on intercepting it beyond

FIG. 276.



Diffraction.

the focus of the lens, by means of an opaque screen, *e*, with a sharp edge, *a* (a knife-blade, for example), the following appearances arise.

1st. The edge *a* does not cast a sharply defined or geometrical shadow upon the second screen, *b*, of which B is a front view, where it is cut by the plane, the edge of which is represented by the line *a b*, but a faint light appears below this, and gradually fades away. The rays in passing over the knife-edge, have, therefore, been bent downwards.

2d. The part of the screen above the line where it is cut by the plane *a b*, we should expect to be uniformly lighted, but this is not so; it presents a series of alternate red and dark bands or fringes, which are fainter as we pass above the plane *a b*, until they finally disappear. The limits between these are not sharp lines, but the bands are regions of maximum and minimum intensity, which gradually fade into each other

3d. In the first of these there is a bending downwards of the rays, whereby a part of the geometrical shadow has been illuminated. The same has also occurred in the second, and it is to this action which an edge impresses upon rays of light that the term diffraction is applied.

4th. Light of every color shows the same phenomena, but the fringes are broader in the red, and become narrower as we pass through the spectrum towards the violet. In white light, therefore, the dark spaces of one spectrum color are illuminated by the light of the next, and thus an image composed of a series of colors is formed.

607. Diffraction Spectra.—If the experiment in the last article is modified, causing the pencil of light from the luminous point to pass through a narrow slit in a screen, and the image viewed through a telescope, or allowed to fall on white paper, the following phenomena appear. The light being red, the image consists of a red band, on the right and left are alternate red and dark bands, the former gradually fading away. The series on both sides are alike in intensity and extent. As in (605), their breadth differs with the tint of the light. If white light is substituted for monochromatic, a series of similarly placed spectra appear on each side of the central bright line.

If in place of a simple slit a number of parallel linear openings are made by stretching fine wire backwards and forwards across an opening, or by making exact parallel rulings on smoked glass, the spectra become greatly increased in intensity. The violet end of each spectrum is towards the central bright image and the red end outwards. The length or dispersion of the spectra increases with their distance from the central image, consequently they overlap each other, and unless special contrivances are employed only the first, second, and part of the third can be used.

Rulings are also made by a diamond upon metal or glass, and are called *gratings*. In the former they are used by reflection, in the latter by transmission, or, if the glass is silvered, the grating thereon may be used in the same manner as if it were metallic. According as the number of lines to the inch increase, it gives spectra of greater dispersion and further apart, or at a greater angle to the central bright bar.

These are called *diffraction* or *interference spectra*, and, as in sunlight, the colors and dark lines are placed according to their wave lengths, they are also called *normal spectra*.

Since in the diffraction spectrum the red undergoes more dispersion than in the prismatic, it is better adapted for investigations regarding the absorption spectra of various animal

fluids, the dark bands they produce lying chiefly below the yellow and in the red region.

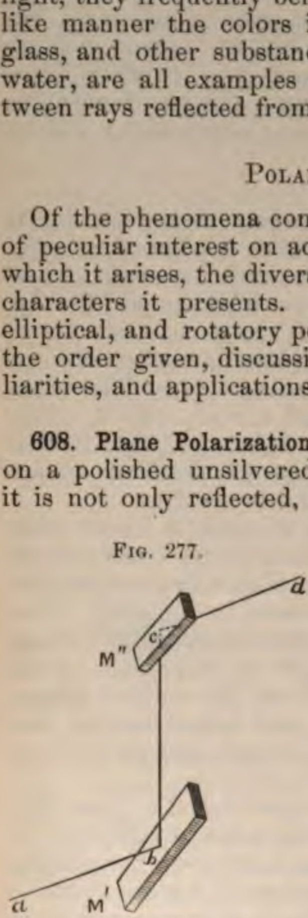
The brilliant iridescence or play of tints on certain shells and other surfaces, is caused by interference decomposition of light, they frequently being ruled like a metallic grating. In like manner the colors in a soap bubble, in thin films of mica, glass, and other substances; in fissures in glass, and in oil on water, are all examples of color produced by interference between rays reflected from their two surfaces.

Polarization of Light.

Of the phenomena considered in this Chapter, polarization is of peculiar interest on account of the various conditions under which it arises, the diverse effects it produces, and the different characters it presents. Light may undergo plane, circular, elliptical, and rotatory polarization; these we shall examine in the order given, discussing their manner of production, peculiarities, and applications.

608. Plane Polarization by Reflection.—If a ray of light falls on a polished unsilvered glass surface, at an angle of 35° 25′, it is not only reflected, but undergoes another extraordinary change; for if the reflected ray is received at the same angle upon another sheet of similar glass, it is most completely reflected when the face of the second mirror is parallel to that of the first, as in Fig. 277, in which a is an incident ray of ordinary light reflected from the mirror M′, in the direction $b\,c$; on meeting the second mirror M″ at c, it undergoes reflection, following the line $c\,d$; on rotating the mirror M″ on its vertical axis, the reflected ray loses its intensity, and when M″ has moved through 90°, the light falling on its surface from M′ is no longer reflected.

Fig. 277.



Polarization.

To this change in the ray $b\,c$, in consequence of which it can only be reflected under certain conditions, and fails entirely in others, the term *polarization* is applied. The first mirror is called the *polarizer*, and the second, on account of its action, the *analyzer*.

609. Angle of Polarization is that which the incident ray must make with the normal or perpendicular to the polished surface

of any given substance, to produce complete polarization in the ray reflected from it. In glass, it is 54° 35′, or the complement of the angle given. If in Fig. 277, any other angle than this is given to the first mirror, the light reflected from it is not completely polarized, as is proven by the fact that a portion will always undergo reflection from the second, in whatever position it may be placed. Under these conditions the reflected ray is said to be partially polarized.

Nearly all surfaces possess the power of partially polarizing light. That reflected from water, a polished wooden surface, or a slate roof, is partially polarized; diffuse daylight is also found to have assumed this condition, especially when the sun is near the horizon.

With difference in the nature of the substance there is change in the angle of polarization. For glass, it is 54° 35′; water, 52° 45′; obsidian, 56° 30′; quartz, 57° 32′; and for diamond, 68°. Different kinds of glass also show variation in the angle of polarization; between crown and flint glass it is frequently as much as a degree and a quarter.

According to Brewster: "*The polarizing angle of any substance is that angle of incidence at which the reflected polarized ray is at right angles to the refracted ray.*

"The *plane of polarization* is the plane of reflection in which the light becomes polarized; it coincides with the plane of incidence, and, therefore, contains the polarizing angle."

610. Polarization by Single Refraction.—If the ray which passes through the glass, in the experiment (608), is submitted to examination by a second mirror in the same manner as the ray *b c*, it is polarized, though the action is only partial. At the same time it has undergone a certain amount of refraction. We, therefore, learn that in simple refraction polarization also occurs.

611. Polarization by Double Refraction.—We discovered (603, 604) that when a ray of light traverses a crystal of Iceland spar in certain lines, it undergoes double refraction, an ordinary and extraordinary ray being formed. If these are submitted to examination by an analyzer, it is found that they are composed of polarized light. The polarization in the two instances is, however, different, in that their planes are at right angles to each other. The position in which the analyzer gives complete passage to the ordinary ray, is the one in which it gives most complete denial to the passage of the extraordinary.

612. Polarizing Instruments.—1st. *Norremberg's apparatus* is constructed upon the principle of polarization by reflection;

the polarizer and analyzer being single plates of polished glass. It is a most simple and a very complete polarization apparatus, and can be used for demonstrating nearly all the experiments.

2d. *Apparatus of parallel plates.* Though the proportion of polarized light in the refracted pencil (610) is small when the ray passes through a single plate of glass, it is increased by using a number of films or plates arranged parallel to the first. The surfaces must be as flat as possible, and parallel to each other. In this manner, good polarizers and analyzers built up of fifteen or twenty plates of glass made for microscope object-covers can be constructed at small expense; the plates being fitted at the proper angle into a metallic or wooden tube. Either the reflected or refracted ray from such bundles is used.

3d. *Tourmaline.* If a plate be cut parallel to the axis of this negative uniaxial crystal, it produces an ordinary and an extraordinary ray polarized in planes at right angles to each other. The plate also possesses the property of rapidly absorbing the ordinary ray, if, therefore, it has sufficient thickness, the extraordinary alone will escape. A second similar plate may be used as an analyzer; through such an arrangement the light which has been polarized by the first plate passes with but little loss, while the second is set parallel to the first; but is completely stopped when they are at right angles.

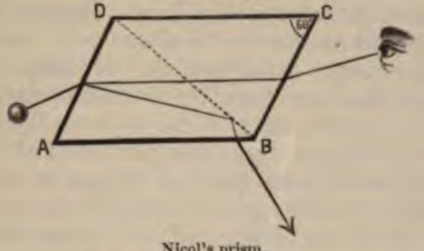
The thickness required to cause complete absorption of the ordinary ray is a serious objection to the use of tourmaline plates, on account of the great loss of light it necessitates.

4th. *Double refracting prisms.* The ordinary and extraordinary rays which emerge from a natural rhomb of Iceland spar, are parallel to each other; the amount of their separation, therefore, is dependent upon the thickness of the prism. The extent of this can be increased by cutting the crystal until its faces are inclined. In the prism thus formed, though the desired separation may be obtained, a new difficulty arises, the emergent light being colored by decomposition. To remedy this evil, it is necessary to achromatize the prism by uniting it with one of glass, with its refracting angle in the opposite direction. To obtain the greatest divergence between the rays, the refracting edges are cut parallel to the optic axis.

A prism such as that described, generally permits the emergence of an ordinary and extraordinary ray, the relative intensities of which vary as it is revolved. There are, however, two positions in which only the ordinary ray emerges, and two others at right angles to these in which the extraordinary alone escapes. The apparatus, therefore, not only informs us whether the light is polarized, but also the plane wherein the polarization has taken place.

5th. *Nicol's prism* is, for many purposes, the best means of polarizing light, as it is exceedingly transparent, polarizes completely, and transmits only the extraordinary ray. It is made of Iceland spar, and is a column the height of which is about three times its breadth. The crystal is cut in twain along a plane connecting its obtuse angles. The parts are then cemented together with Canada balsam.

FIG. 278.



Nicol's prism.

The principle of action of the Nicol is, that the refractive index of the balsamic cement being less than the ordinary index of the spar, and greater than the extraordinary, the ordinary ray undergoes total reflection at the surface of the balsam, B D, and is refracted out of the crystal at its side, A B, while the extraordinary passing onwards emerges at the end, B C. The Nicol can be used as polarizer or analyzer.

In Foucault's prism the Canada balsam is omitted. While this is shorter, it has the disadvantage of giving a smaller field of view, and the loss of light by reflection is greater.

613. Theory of Polarized Light.—It has been stated in (441), that luminous vibrations are transverse, while those of sound are longitudinal. This hypothesis regarding the manner of vibration of the ethereal particles in the production of light is supported by the phenomena of polarization.

Considering the double refraction action of Iceland spar, Ganot says, "Now it can be shown to be in strict accordance with mechanical principles that, if a medium possesses unequal elasticity in different directions, a plane wave produced by transversal vibrations entering that medium will give rise to two plane waves moving with different velocities within the medium, and the vibrations of the particles in front of these waves will be in directions parallel respectively to two lines at right angles to each other. If, as is assumed in the undulatory theory of light, the ether exists in a double refracting crystal in such a state of unequal elasticity, then the two plane waves will be formed as described, and these, having different velocities, will give rise

to two rays of unequal refrangibility. This is the physical account of the phenomenon of double refraction. It will be remarked that the vibrations corresponding to the two rays are transversal, rectilinear, and in directions perpendicular to each other in the rays respectively. Accordingly, the same theory accounts for the fact that the two rays are both polarized, and in planes at right angles to each other."

614. Interference of Polarized Light.—The laws which govern the phenomena of interference of rays similarly and differently polarized, are stated as follows by Ganot:

"1. When two rays polarized in the same plane interfere with each other, they produce by their interference fringes of the very same kind as if they were common light.

"2. When two rays of light are polarized at right angles to each other, they produce no colored fringes in the same circumstances under which two rays of common light would produce them. When they are polarized in planes inclined to each other at any other angles, they produce fringes of intermediate brightness, and if the angle is made to change, these gradually decrease in brightness from 0° to 90°, and are totally obliterated at the latter angle.

"3. Two rays originally polarized in planes at right angles to each other, may be subsequently brought into the same plane of polarization without acquiring the power of forming fringes by their interference.

"4. Two rays polarized at right angles to each other, and afterwards brought into the same plane of polarization, produce fringes by their interference like rays of common light, provided they originated in a pencil the whole of which was originally polarized in any one plane.

"5. In the phenomena of interference produced by rays that have suffered double refraction, a difference of half an undulation must be allowed, as one of the pencils is retarded by that quantity from some unknown cause."

615. Depolarization—Suppose a polarizing apparatus, with its polarizer and analyzer so adjusted that the passage of light through the latter is completely stopped. Then intervene a plate of double refracting crystal, cut parallel to its axis, and of moderate thickness, between the polarizer and the analyzer. The intensity of the transmitted light varies as the plate is turned, reaching its maximum when the principal plane of the plate is at 45° to the plane of reflection, and disappearing if they coincide, or are at right angles to each other. From the effect produced upon the light transmitted by the polarizer, a plate like that described is called a *depolarizing plate.*

616. Action of Thin Films is thus described by Ganot: "Take a thin film of *selenite* or *mica* between the twentieth and sixtieth of an inch thick, and interpose it as in the last article. If the thickness of the film is uniform, the light now transmitted through the analyzer will be no longer white, but of a uniform tint; the color of the tint being different for different thicknesses—for instance, red, or green, or blue, or yellow, according to the thickness; the intensity of the color depending on the inclination of the principal plane of the film to the plane of reflection, being greatest when the angle of inclination is 45°. Let us now suppose the crystalline film to be fixed in that position in which the light is brightest, and suppose its color to be *red*. Let the analyzer (the Nicol's prism) be turned round, the color will grow fainter, and when it has been turned round 45°, the color disappears, and no light is transmitted; on turning it further, the complementary color, *green*, makes its appearance, and increases in intensity until the analyzer has been turned through 90°; after which the intensity diminishes until an angle of 135° is attained, when the light again vanishes, and, on increasing the angle, it changes again into red. Whatever the color proper to the plate, the same series of phenomena will be observed, the color passing into its complementary when the analyzer is turned. That the colors are really complementary is proved by using a double refracting prism as analyzer. In this case two rays are transmitted, each of which goes through the same changes of color and intensity as the single ray described above; but whatever the color and intensity of the one ray in a given position, the other will have the same when the analyzer has been turned through an angle of 90°. Consequently, these two rays give simultaneously the appearances which are successively presented in the above case by the same ray at an interval of 90°. If now the two rays are allowed to overlap, they produce white light; thereby proving their colors to be complementary."

617. Production of Colored Rings by Polarized Light.—In the preceding experiment, while the rays traverse the film perpendicularly to its faces, the tint is uniform; but if at different obliquities, colored rings are produced. Regarding these, Ganot says:

"The best method of observing these new phenomena is by means of the *tourmaline pincette.* This is a small instrument consisting of two tourmalines, cut parallel to the axis, each of them being fitted in a copper disk. These two disks, which are perforated in the centre, and blackened, are mounted in two rings of silvered copper, which is coiled to form a spring, and press together the tourmalines. The tourmalines turn with the disk,

and may be arranged with their axes either perpendicular or parallel."

"The crystal to be experimented upon, being fixed in the centre of a cork disk, is placed between the two tourmalines, and the pincette held before the eye to view diffused light. The tourmaline furthest from the eye acts as polarizer, and the other as analyzer. If the crystal thus viewed is uniaxial, and cut perpendicularly to the axis, and a homogeneous light—red, for instance—is looked at, a series of alternately dark and red rings are seen. With another simple color similar rings are obtained, but their diameter decreases with the refrangibility of the color. On the other hand, the diameters of the rings diminish when the thickness of the plates increases, and beyond a certain thickness no more rings are produced. If, instead of illuminating the rings by homogeneous light, white light is used, as the rings of the different colors produced have not the same diameter, they are partially superposed, and exhibit very brilliant variegated colors."

Biaxial crystals also give colored rings, but their form is more complicated.

618. Detection of Molecular Change by Polarized Light.—Under ordinary circumstances glass does not possess the power of double refraction. This property may, however, be imparted to it by changing the relations of its molecules either by compression, curvature, or heat. If, under these conditions, a beam of polarized light traverses the glass, the changed conditions of its molecular structure are at once made evident, by the production of colored rings, or curved figures, like those described, the forms of which are according as the piece of glass is circular, triangular, or rectangular, and as the compression or other force is altered in intensity. Some idea may be gained of the changes in question from Fig. 279, which represents the effects produced, as a circular piece of compressed glass is revolved in its own plane between the polarizer and analyzer.

FIG. 279.

Compressed glass and polarized light.

The results we have been discussing show the great importance of polarized light in investigation of questions having relation to molecular structure. Its use in the study of numerous inorganic crystalline forms, and also of organic structures as starch, yields most efficient aid in determining their character when applied in connection with the microscope.

619. Elliptical and Circular Polarization.—" In the cases hitherto considered the particles of ether composing a polarized ray vibrate in parallel straight lines; to distinguish this case from those we are now to consider, such light is frequently called *plane polarized light.* It sometimes happens that the particles of ether describe *ellipses* round their position of rest, the planes of the ellipses being perpendicular to the direction of the ray. If the axes of these ellipses are equal and parallel, the ray is said to be *elliptically polarized.* In this case the particles which, when at rest, occupied a straight line, are, when in motion, arranged in a helix round the line of their original position as an axis, the helix exchanging from instant to instant. If the axes of the ellipses are equal they become circles, and the light is said to be circularly polarized. If the minor axes become zero, the ellipses coincide with their major axes, and the light becomes *plane polarized.* Consequently, *plane* polarized light and *circularly* polarized light are particular cases of elliptically polarized light."

" Circular or elliptical polarization may be either *right-handed* or *left-handed*, or what is sometimes called *dextrogyrate* and *lævogyrate.* If the observer looks along the ray in the direction of propagation, from polarizer to analyzer, then, if the particles move in the same direction as the hands of a watch with its face to the observer, the polarization is right-handed."

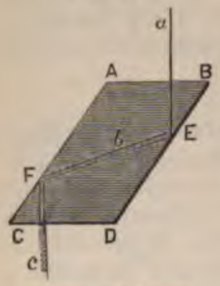
620. Theory of Elliptical and Circular Polarization.—Regarding the relations of elliptical, circular, and plane polarization to each other, Ganot says: " Let us in the first place consider a simple pendulum vibrating in any plane, the arc of vibration being small. Suppose that, when in its lowest position, it received a blow in a direction at right angles to the direction of its motion, such as would make it vibrate in an arc at right angles to its arc of primitive vibration, it follows from the law of the composition of velocities, that the joint effect will be to make it vibrate in an arc inclined at a certain angle to the arc of primitive vibration, the magnitude of the angle depending on the magnitude of the blow. If the blow communicated a velocity equal to that with which the body is already moving, the angle would be 45°. Next suppose the blow to communicate an equal velocity, but to be struck when the body is at its highest point, this will cause the particle to describe a circle, and to move as a conical pendulum. If the blow is struck under any other circumstances, the particle will describe an ellipse. Now as the two blows would produce separately two simple vibrations in directions at right angles to each other, we may state the result arrived at as follows: If two rectilinear vibrations are superinduced on the same particle in directions at right angles

to each other, then: A. If they are in the same and opposite phases, they make the point describe a rectilinear vibration in a direction inclined at a certain angle to either of the original vibrations. B. But if their phases differ by 90° or a quarter of a vibration, the particle will describe a circle, provided the vibrations are equal. C. Under other circumstances the particle will describe an ellipse."

"To apply this to the case of polarized light. Suppose two rays of light polarized in perpendicular planes to coincide, each would separately cause the same particles to vibrate in perpendicular directions. Consequently—A. If the vibrations are in the same or opposite phases, the light resulting from the two rays is plane polarized. B. If the rays are of equal intensity, and their phases differ by 90°, the resulting light is circularly polarized. C. Under other circumstances the light is elliptically polarized."

621. Production of Circularly Polarized Light is accomplished by means of Fresnel's rhomb, which decomposes a ray of plane polarized light forming two equal rays polarized in planes at right angles to each other, but differing by a quarter of an undulation. The instrument is made of glass, the acute angle being 54°, and the obtuse 126°. "If a ray, *a*, Fig. 280, of plane polarized light falls perpendicularly on the face A B, it will undergo two total internal reflections at an angle of about 54°, one at E, and the other at F, and will emerge perpendicularly to C.

FIG. 280.



Circular polarization.

"If the plane A B C D be inclined at an angle of 45° to the plane of polarization, the polarized ray will be divided into two coincident rays, with their planes of polarization at right angles to each other, and it appears that one of them loses exactly a quarter of an undulation, so that on emerging from the rhomb the ray is circularly polarized. If the ray emerging as above from Fresnel's rhomb is examined, it will be found to differ from plane polarized light in this, that, when it passes through a double refracting prism, the ordinary and extraordinary rays are of equal intensity in all positions of the prism. Moreover, it differs from ordinary light in this, that if it passed through a second rhomb placed parallel to the first, a second quarter of an undulation will be lost, so that the parts of the original plane polarized ray will differ by half an undulation, and the emergent ray will be plane polarized; moreover, the plane of polarization will be inclined at an angle of 45° to A B C D, but on the *other side* from the plane of primitive polarization."

622. Production of Elliptically Polarized Light.—"In addition to the method already mentioned, elliptically polarized light is generally obtained whenever plane polarized light suffers reflection. Polarized light reflected from metals becomes elliptically polarized, the degree of ellipticity depending on the direction of the incident ray, and of its plane of polarization, as well as on the nature of the reflecting substance. *When reflected from silver the polarization is almost circular, and from galena almost plane. If elliptically polarized light be analyzed by a Nicol's prism, it never vanishes, though at alternate positions it becomes fainter; it is thus distinguished from plane and from circular polarized light. If analyzed by Iceland spar neither image disappears, but they undergo changes in intensity.*"

"Light can also be polarized elliptically in Fresnel's rhomb. If the angle between the planes of primitive polarization and of incidence be any other than 45°, the emergent ray is elliptically polarized."

623. Production and Theory of Rotatory Polarization.—"Rock-crystal or quartz possesses a remarkable property which was long regarded as peculiar to itself among all crystals, though it has been since found to be shared by tartaric acid and its salts, together with some other crystalline bodies. This property is called rotatory polarization, and may be described as follows: Let a ray of homogeneous light be polarized, and let the analyzer, say a Nicol's prism, be turned till the light does not pass through it. Take a thin section of a quartz crystal cut at right angles to its axis, and place it between the polarizer and the analyzer, with its plane at right angles to the rays. The light will now pass through the analyzer. The phenomenon is not the same as that previously described, for, if the rock-crystal is turned round its axis, no effect is produced, and if the analyzer is turned, the ray is found to be *plane polarized* in a plane inclined at a certain angle to the plane of primitive polarization. If the light is red, and the plate one millimetre thick, this angle is about 17°. In some specimens of quartz the plane of polarization is turned to the right hand, in others to the left hand. Specimens of the former kind are said to be right-handed, those of the latter kind left-handed. This difference corresponds to a difference in crystallographic structure. The property possessed by rock-crystal of turning the plane of polarization through a certain angle was thoroughly investigated by Biot, who, amongst other results, arrived at this: For a given color the angle through which the plane of polarization is turned is proportional to the thickness of the quartz. The explanation of the phenomenon described is as follows: When a ray of polarized light passes along the axis of the quartz crystal, it is divided into two rays

of *circularly* polarized light of equal intensity, which pass through the crystal with different velocities. In one the circular polarization is right-handed, in the other left-handed, The existence of these rays was proved by Fresnel, who succeeded in separating them. On emerging from the crystal, they are compounded into a plane polarized ray, but since they move with unequal velocities within the crystal, they emerge in different phases, and consequently the plane of polarization will not coincide with the plane of primitive polarization. The plane of polarization will be turned to the right or left, according as the right-handed or left-handed ray moves with the greater velocity. Moreover, the amount of rotation will depend on the amount of retardation of the ray whose velocity is least—that is to say, it will depend on the thickness of the plate of quartz."

624. Coloration by Rotatory Polarization.—For different colors the amount of rotation varies according to the refrangibility of the rays, being greatest for the violet. A quartz plate one millimetre thick will rotate the plane 17° for red, and 44° for violet light. If white light is used, it undergoes decomposition, the colors appearing in order from the less to the more refrangible with a right-handed crystal, as the Nicol is turned to the right, and with a left-handed crystal in the opposite order.

FIG. 281.

Rotatory polarization.

If, in place of a Nicol, a double refracting prism is used, two brilliant colors are produced which are complementary to each other and yield white light where they overlap. Fig. 281.

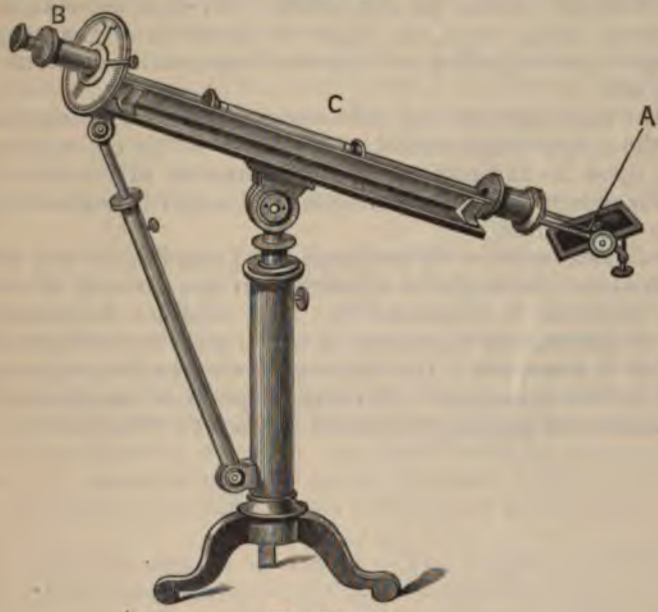
625. Rotatory Power of Liquids.—Many liquids possess this power in different degrees, and in several directions, so that variations in composition may thereby be found when little or none is shown by chemical analysis. If, for example, cane sugar is acted upon by dilute acids, we obtain two sugars of the same chemical composition, but one rotates the plane of polarization to the right, while the other turns it to the left.

In fluids the power of rotation is much less than in quartz. In concentrated solution, cane sugar, the most powerful of all liquids in this respect, has only about $\frac{1}{40}$th the power of quartz; in order, therefore, to give it sufficient influence over the ray, columns eight inches in length are employed.

626. Saccharimeters are instruments depending upon polarized light for their action. That of Biot determines the amplitude of rotation produced by sugar or other solutions possessing this power. The polarizer in the original form is a mirror of

black glass, and the analyzer a double refracting achromatic prism mounted in the interior of a graduated circle, so that changes in position of the prism are read by means of an index traversing the scale Between these the tube containing the solution is placed, with its axis coincident with the conjoined

FIG. 282.



The polariscope.

axes of the analyzer and polarizer. The tube is about 20 centimetres in length. The apparatus is adjusted to have the extraordinary ray disappear when the index is at zero. The introduction of water, alcohol, or ether causes no change in the phenomena observed.

If it is then filled with a solution of cane sugar the extraordinary ray reappears, and to cause it to fade the analyzer must be turned to the right of zero through a certain number of degrees, which measures the amount that the sugar has *turned* the plane of polarization to the left. If a longer tube be used with a solution of the same strength the analyzer must be turned through a greater number of degrees. According as the strength of the solution differs, so does the angle at which the analyzer must be set vary. It is, therefore, a simple matter to estimate the amount of sugar in any given solution by determining its power to rotate a beam of polarized light.

Since white light is decomposed in the preceding experiment, the extraordinary image is not entirely extinguished in any position of the analyzer. This difficulty is met by using colored glass, or other medium which shall make the light monochromatic. The colors usually employed are either red or yellow; the latter is best obtained by means of a soda flame produced by immersing a platinum wire bearing a globule of biborate of soda in a Bunsen flame. Since the angle differs for each color used, it is mentioned along with the angle of deviation of the ray, and the sign +, or —, added to show whether rotation is to the right or the left.

In the manufacture and refining of sugar, the saccharimeter is of the utmost importance, as the sales of this commodity are based upon its indications. In the practice of medicine it is used for determining the percentage of sugar in diabetic urine, and in other fluids.

Soleil's saccharimeter differs from the preceding in that it does not measure the angle of rotation, but the amount of *compensation* required to overcome it. The medium employed is a plate of quartz, the thickness of which may be varied until the rotation is overcome; the amount necessary to produce this result is then measured. For a description of the parts of this instrument the student is referred to Ganot's "Physics."

CHAPTER XXVIII.

SPECTROSCOPE AND SPECTRUM ANALYSIS.

The spectroscope—Parts of single prism spectroscope—Slit and collimator—Prism and telescope—Scale of collimator—Sources of light—Multiple prism spectroscope—Direct vision spectroscope—Grating spectroscope—Continuous spectra—Bright-lined spectra—Banded spectra—Nebular spectra—Gaseous absorbent spectra—Solar spectrum—Ultra-violet solar spectra—Infra-red solar spectra—Wave-lengths of lines of spectra—Use of solar lines as a scale—Atmospheric spectrum lines—Planetary and stellar spectra—Absorbent spectra by colored liquids—Absorbent spectra by colorless liquids—Blood spectra—Spectra of bile and Pettenkofer's fluid—Spectra of wine and ale. Abnormal spectra.

627. The Spectroscope, as its name indicates, is an instrument for studying the composition of light by the formation of a spectrum. In (500 to 505) we learned how light can be de-

composed by the action of an optical prism, and its character determined through the formation of a prismatic spectrum. In (607) the decomposition of light by a ruled surface or grating was explained, and also the difference between the diffraction or interference spectrum thereby produced and the prismatic spectrum. Either of these methods can be employed in the construction of the spectroscope, but thus far the one in general use has been that by the prism; we shall, therefore, direct our attention especially to this form.

The action of the spectroscope being to separate or disperse a mixture of colors into its components, it follows that an amount of dispersion which will answer in one case may be insufficient in another. We consequently find that, according to the dispersion required, the spectroscope contains one or more prisms arranged as described in the final paragraph of article (502).

628. Parts of Single Prism Spectroscope.—This form of instrument will generally answer for the physiologist and physician. It consists of a prism upon which the axes of three telescopes are directed; a narrow slit, and a scale for measurement of the relative positions of lines or colors. Of the telescopes one is attached to the slit, its lens forms the *collimator;* another receives and transmits the spectrum image formed by the prism, it is called the *observing telescope;* the third forms an image of the scale. In considering these parts, we shall take them up in the order which the light passes through them to the eye.

629, The Slit and its Collimator.—The bright and dark lines visible in the spectroscope are images of the slit. .This is situated at 1, Fig. 283. It consists of two sharp metallic edges set at a short distance from each other, allowing a narrow beam of light to pass between them into the tube to which it is attached. These must be perfectly true and smooth, like those of a knife, and set exactly parallel to each other. They should be protected from dust, and as they are commonly made from steel, care should be taken to prevent their rusting by moisture or fumes. Dust or rust upon their edges produces longitudinal striæ in the spectrum. To avoid rusting, they are sometimes made of *obsidian*.

In its simplest form the jaws are at a fixed distance from each other, and the width of the beam of light admitted to the eye is invariable. In more improved kinds one of the jaws is moved by a screw, so that the slit may be entirely closed or opened to any required extent. Sometimes the screw head carries a scale and index, by which the aperture can be measured, and changed or restored at will.

In ordinary use the slit is placed quite close to the flame to

be examined, and so adjusted that the latter is in the vertical axial plane of the tube which carries the slit, as at 7, Fig. 283. When necessary to compare the spectra of two flames, one-half of the vertical aperture is covered by a small prism so adjusted, that if the second is placed at one side of the first, its rays will be directed down the tube, and while those from one source of

FIG. 283.

The spectroscope.

light occupy the upper half of the vertical axial plane, those from the other occupy its lower half. Thus two spectra are presented to the observer one immediately above the other, and their minutest details may be accurately compared. The device is known as the *comparison prism*.

In the spectrum apparatus of Fraunhofer the slit was placed at a distance of twenty-four feet from the prism, presenting a nearly parallel beam of light to its action. A great improvement was made upon this by Prof. Swan, who achieved the same result by means of a convex lens called the *collimator*, placed at its principal focal distance from the slit, and with its exposed face close to the prism. It is located at 2, Fig. 283. The slit and collimator are mounted in a tube provided with a second or draw tube, thus allowing any focal adjustment.

630. The Prism and Telescope are for the formation and examination of the spectrum. The former occupies the position at 3, Fig. 283. It is usually equiangular or a prism of 60°. It is set at its angle of minimum deviation (499). According as

greater or less dispersion is desired it differs in its character. One of crown glass gives a moderate dispersion; ordinary flint a greater, and heavy glass a still greater. Hollow prisms filled with liquid, as the bisulphide of carbon, are also employed.

The observing telescope is represented at 4. It is supported on a movable arm, in order that any portion of the spectrum image emerging from the prism can be passed down its axis, and submitted to examination under the most favorable conditions.

631. The Scale and its Collimator.—These are shown at 5 and 6, and form the third telescope of the apparatus. The former is at the outer end, and is usually photographed upon glass. It is illuminated by a candle or other flame, as at 6; at the inner end at 5, there is a convex lens or collimator, from this the rays from the illuminated scale are directed upon the face of the prism adjacent to the object-glass of the telescope, in such a manner, that they are reflected down its axis, and a bright image of the scale is seen above or below the spectrum, according to the direction given to the axis of the scale tube.

Another method consists in placing the scale immediately in front of the eye-piece and illuminating from one side by a peculiarly constructed prism, which accomplishes the object by two reflections.

In some instruments a micrometer eye-piece is used, as in the microscope. In others, the arm supporting the observing telescope traverses over a graduated arc. The positions of the lines in the spectrum are determined thereon by bringing the cross-wires of the eye-piece of the telescope to intersect them, and reading the degree on the arc.

632. The Source of Light.—When sunlight is employed, it must be directed by a mirror upon the slit along the axis of its collimator-tube. The beam should be made steady by a heliostat.

For ordinary chemical examinations a Bunsen flame is used in the position indicated at 7. Into this the substance is introduced by means of a platinum wire, supported by a stand, as at 8.

If a more intense heat than that furnished by a Bunsen flame is required, an oxyhydrogen jet may be substituted, and in the same position. For still greater intensity the electric spark, either derived directly from an induction apparatus, or concentrated by a condenser, is employed.

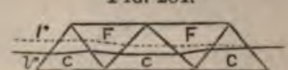
633. Multiple Prism Spectroscope is composed of a number of prisms acting in the same direction, and so arranged that they can all be adjusted for their angle of minimum deviation for any ray. In some forms light passes in one direction through

the battery of prisms, and in the last of the series is made to undergo reflection, by which it is returned through the same system. Thus an amount of dispersion is attained equal to that produced by double the number of the effective prisms. Spectroscopes of this nature are only used for special astronomical investigations. Sometimes a double prism instrument is desirable in certain chemical examinations.

634. Direct Vision Spectroscope.—It has been stated in (502) that the dispersion power of flint glass is nearly double that of crown. The difference in their deviation power is at the same time not so great. It is, therefore, possible to combine a number of these prisms in such a manner, that while the ray of light undergoes little or no deviation from its original course, there is sufficient dispersion between its colors to produce a spectrum available for spectroscopic uses.

In Fig. 284, such an arrangement is represented. It consists of three crown prisms marked C C C, and two flint marked F F. The two kinds are so adapted to each other, that their bases being in opposite directions, they neutralize each others

FIG. 284.



Direct vision spectroscope.

action. In respect to deviation, this neutralization is perfect. As regards dispersion, it is not, consequently the component colors of white light are separated in its passage through the system, as at $r\ v$: and a spectrum is formed.

635. Grating Spectroscope.—In (607) the production of diffraction or interference spectra by means of gratings was described. Though in this method of formation there is a decided loss of light, the original beam being divided into a great number of spectra, there is a gain in the greater dispersion obtained in the red region.

For physiological purposes a grating of about 5000 lines to the inch, ruled on glass, the surfaces flat and parallel, is substituted for the prism, and mounted in its place.

The best form of spectroscope to accomplish this is that in which measurements are made by traversing the telescope upon a graduated circle. The grating may be mounted either for transmitted or reflected light. In the former the adjustments are as follows:

1st. The graduated circle being placed in the horizontal plane, the narrow opening of the slit should be set vertically.

2d. The centre of the slit, the axis of its collimator-tube, the axis of the telescope, and the intersection of its cross-lines being in the same straight line, the index of the telescope should point to the zero of the graduated circle.

3d. The unruled surface of the grating should be turned towards the collimator, and set so that the axis of the latter shall be perpendicular to the ruled surface and pierce its centre.

4th. The position of the grating face should be so adjusted, that if its central line was prolonged vertically downwards, it would coincide with the centre of the axis upon which the observing telescope moves.

The above adjustments having been carefully attended to, if the telescope is moved to the right a spectrum will appear, the violet being the first to enter the field, color after color passes in review, then a blank space; then a second spectrum enters, the violet in the van. This is more dispersed than the first, so a third, fourth, and higher orders of spectra display themselves as the telescope is moved onwards. In these, owing to greater dispersion, they overlap each other, and the colors are very much confused; they are also very faint. For most purposes the first and second orders will be found the most useful. If required to separate the colors in the higher orders, it can be done by a prism.

If the telescope is returned to the zero of the scale, and traversed to the left the same phenomena occur, and a similar series of spectra appear. Taking a given line in that produced by sunlight, or the sodium line in that from a flame; if the apparatus is sufficiently perfect in the construction of all its parts, it will be found that the telescope must be moved through the same angle on each side of the zero, to bring the selected line of a spectrum of an order of the same number upon its cross-lines.

Where it is desired to use the grating for reflected light, its ruled surface must be silvered. Spectra of greater brilliancy are thus produced. It is, however, necessary to set the grating at an angle to the axis of the slit collimator, and swing the telescope to the collimator side of the circle.

In making photographs of the solar spectrum by a silvered grating I resorted to the device of passing the beam of light from the slit beneath the grating, and then reflecting it from a plane silvered mirror upon the grating. For a description of the method and results, the student is referred to the "American Journal of Sciences and Arts," vol. xvi. page 256.

Spectrum Analysis.

Four kinds of spectra present themselves for investigation: 1st, continuous or unbroken; 2d, bright-lined and banded; 3d, absorbent; 4th, abnormal.

636. Continuous Spectra are produced by light emitted from ignited or incandescent solids and liquids. If a body is at low red heat the spectrum consists of red only, or at the best of red and orange; as the temperature rises colors of greater and greater refrangibility appear in their proper order, until finally the seven colors of Newton are present (501). Ordinary illuminating flames, in which carbon at a high temperature is the source of light, furnish excellent examples of this class. Where greater brilliancy is required, the light produced by causing the oxyhydrogen flame to impinge upon a cylinder of lime, magnesia, or zirconia may be used. That from a strip of platinum or carbon rendered incandescent by an electric current is also employed. Continuous spectra are chiefly of interest to the physician, because they furnish a basis for the production of absorbent spectra of various animal fluids. For this purpose any oil or illuminating gas flame answers.

637. Bright-lined Spectra.—If a Bunsen burner be placed in front of the slit of a spectroscope, and access of air be cut off by the valve, an illuminating flame will be produced which on being viewed through the instrument will give a continuous spectrum of incandescence. Admitting air to it, its luminosity will at once disappear, on account of the complete combustion of carbon; it becomes a pale blue and violet and is known as the Bunsen flame. Looking through the spectroscope a spectrum will no longer be visible, or at best only a very faint light in the more refrangible region.

If a platinum wire dipped in a solution of chloride of sodium or common salt, be immersed in the Bunsen flame, the latter becomes yellow, and on looking through the spectroscope a bright yellow line appears in the space formerly occupied by the yellow of the incandescent spectrum. This is known as the sodium line. With a spectroscope of feeble dispersion it is single; but when two or more prisms are used, with a slit sufficiently narrow, it appears as a double line. When a heat more intense than from an ordinary Bunsen burner is employed other lines appear in the sodium spectrum and it finally becomes continuous. So delicate is this test for *sodium*, that it has been estimated that the two hundredth-millionth of a grain of that

element can thus be detected. Indeed in this respect it stands first among all metals.

In their turn many other substances give special colors to the Bunsen flame, and these when viewed through the spectroscope present characteristic spectra composed of bright lines. So that of *potassium* produced in the same manner as that of sodium, consists of a red and a violet line. *Calcium*, *lithium*, *strontium*, and *rubidium*, all present strongly marked lines in certain positions in the red together with other lines. *Cæsium* gives a characteristic blue line; *thallium* a green; *indium* an indigo. The great value of the spectroscope in chemical research is emphasized by the fact, that within a few years a number of new elements have been discovered by its aid; among these, the first were cæsium and rubidium, and later thallium, indium, and gallium.

Since chlorides of metals are as a rule more volatile than other compounds, these salts should be employed to show their spectra. It is also well to moisten the platinum wire with a drop of hydrochloric acid before dipping it into the pulverized salt. In the form of chloride, copper gives a superb spectrum when immersed in Bunsen flame, and so do certain other ordinary metals.

An immense advantage possessed by spectrum analysis over all other methods of investigation into the composition of a body is the fact, that it yields almost at a glance all the information it is capable of affording. Suppose, for example, in place of a single element we have a mixture, as sodium, potassium, lithium, calcium. Since each of these presents its own characteristic lines, none of which are coincident with those of the others, we detect the presence of each and all at once, exactly as we recognize the faces of different persons with whom we are acquainted, though mingled with a crowd of others.

For accurate placement of the lines of any element by a given spectroscope, they must be studied in connection with the scale, and a record kept, to which reference can be made. The instrument being then adjusted with the sodium line always on a given line of the scale, the position of the lines found is read off, and their nature determined by reference to the record.

While many metals give strong spectra at the temperatures reached by the Bunsen flame, there are others, like iron, which are not sufficiently volatilized at that heat to give a result. These can all be made to assume the vaporous state by aid of the electric arc, or by the simple or condensed spark of an induction coil. By one or another of these agents, spectra of all the elements have been obtained, that of each being often different according to the temperature at which it is volatilized. For the physician, however, who desires to examine the ash of tissue or excretions for certain elements, the use of lined spectra

is confined to the detection of calcium, sodium, lithium, and other substances volatile in the Bunsen flame. The more potent appliances are, therefore, left almost entirely in the hands of the chemist and physicist.

638. Banded Spectra.—In place of lines, the spectra of some gases and vapors are composed of bright bands. This is the case with the spectrum of cyanogen. Ignited nitrogen affords another example of the same result. Under an increase of temperature bands are broken up into fine lines, sometimes of greater and sometimes less refrangibility than those from which they were formed. It is thought that at lower temperature bands may arise from some compound of a substance, while at higher these may be dissociated, and the true bright lines of the element appear.

The spectra of gases are best obtained by the aid of *Geissler's* and *Plucker's tubes*, which contain the gas or vapor in a state of extreme exhaustion. Those generally employed consist of two elongated bulbs connected by a capillary tube. A platinum electrode passes through the distal end of each, and affords connection with the poles of an induction coil, or a Holtz apparatus. On passing the sparks the slender column of attenuated gas in the capillary tube becomes brilliantly illuminated, and placed in front of the slit, the spectrum under the prevailing conditions is seen.

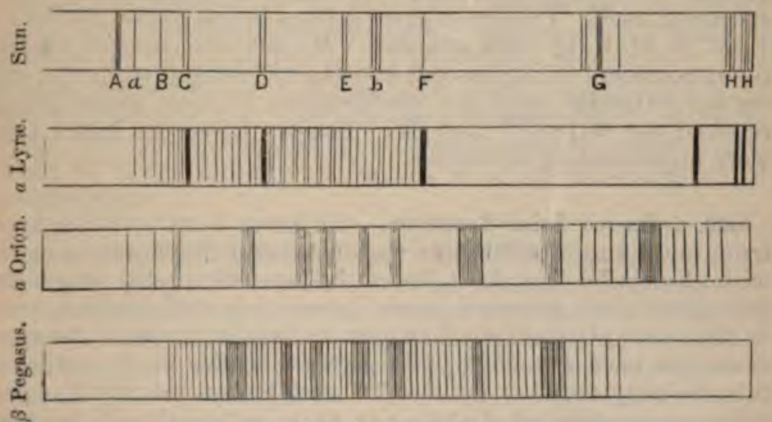
639. Nebular Spectra.—The importance of the application of spectrum analysis to investigating the chemical constitution of the heavenly bodies was quickly recognized by a number of astronomers. It was observed that there was a marked difference between the spectra of the various nebulæ, and those of the fixed stars and planets; in that the former generally gave bright-lined spectra like those of ignited gases, while the latter gave continuous spectra crossed by dark lines.

640. Gaseous Absorbent Spectra.—A sodium flame produces a spectrum consisting of a bright yellow line. It might be expected, that if this was interposed between an oxyhydrogen lime-light and the spectroscope through which it is viewed, the yellow of the former would intensify that of the continuous spectrum of the latter. Such, however, is not the case; on the contrary, the sodium flame absorbs the yellow of the calcium light, and a dark or black line appears in its place. In the same manner potassium, strontium, and other vapors were found to produce dark lines in a continuous spectrum, when intervened between the spectroscope and an oxycalcium light. To this class of phenomena the term *absorbent spectra* is applied, and

it was soon proven, that whenever an incandescent vapor forms a spectrum of bright lines, it will produce a reverse spectrum of dark lines when intervened between the spectroscope and an incandescent solid or liquid.

641. Solar Spectrum.—If a spectroscope be directed towards the sun, or if sunlight be reflected down the tube, while the slit is wide open a very brilliant continuous spectrum is seen. On reducing the aperture the intensity of color diminishes, and when sufficiently narrow well-marked dark lines appear as shown, Fig. 285. These are known as the *Fraunhofer lines*, and

FIG. 285.



Solar and stellar spectra.

were named by their discoverer A B C D, etc. Continuing the reduction in aperture and increasing the dispersive power, these lines appear by thousands.

For long, the origin of the dark lines of the solar spectrum was an inexplicable riddle; but at last the enigma was solved through agency of the facts with which we have been dealing. It was the fortune of Kirchoff to discover that the strong dark line in the yellow of the solar spectrum, which Fraunhofer called D, was coincident with the yellow line of sodium. He, therefore, argued that since incandescent sodium vapor produced a dark line in the spectrum of incandescence from a lime-light, it was evident that in the sun the light emitted from the interior photosphere must meet with sodium vapor in the exterior envelopes, and so by absorption produce the dark line in question. In like manner, the lines C and F were found to be coincident with and a reversion of two hydrogen lines, and over one hundred bright lines of the spectrum of iron were found to have their counterparts in dark lines of the solar spectrum.

Little by little observations were extended until the conviction forced itself upon all scientific minds, that by aid of spectroscopic examination of their light, information could be obtained regarding the chemical constitution of the heavenly bodies, and as the new science underwent extension, it was proved that nearly all substances existing on our earth are discoverable in the exterior envelopes of the sun.

642. Ultra-violet Solar Spectrum.—The original Fraunhofer lines are confined to the visible spectrum, and terminate in the violet at H. By application of photography to the study of the spectrum, it was found that there existed beyond the violet an ultra-violet region, as rich in absorption lines as the visible spectrum itself. To certain great groups in this region the letters L, M, N, O, P, Q, were attached. By use of screens of various phosphorescent or fluorescent substances, the spectrum was still further extended until the enumeration of these great groups reached the letters V and W. Besides these the lesser lines were numbered by thousands.

643. Infra-red Solar Spectrum.—As there is an invisible spectrum in the more refrangible region beyond the violet, crowded with absorption solar lines, so in the less refrangible below the red there is an infra-red space presenting well-marked lines. In this, also, photography has been the agent by which the spectrum has been extended. To give some idea of the extent of this, we may say that between A and H lies the visible spectrum, about 4000 of Augström's units in length. If we take this as representing the visible spectrum, that below extends six times as far, or through 24,000 units, most of which has been mapped.

644. Wave-lengths of the Lines of the Spectrum.—To avoid confusion arising from use of prisms and scales of varying values, attached to different instruments, a scale based upon the wave-lengths of the solar lines has been introduced. The unit is the tenth metre. According to this the wave-lengths of the principal Fraunhofer lines are:

A = 7604.00	b = 5172.00
a = 7185.00	F = 4860.72
B = 6867.00	G = 4307.25
C = 6562.01	H_1 = 3968.00
D = 5892.12	H_2 = 3933.00
E = 5269.13	

645. Use of the Solar Lines as a Scale.—In (631) mention has been made of the ordinary methods of measuring the position

of lines in a spectrum. In the ultra-violet and infra-red these are sometimes difficult of application or fail us altogether. In this, and, indeed, in nearly all cases, the dark lines of the solar spectrum provide the most reliable method by which the position of a given band or line can be satisfactorily determined. One way of applying it is to pass into the observing telescope two spectra, one above and coincident with the other. The first derived from the sun by turning its rays into the collimator by a comparison prism The second from the light to be compared therewith. When the lines of the visible spectrum are to be examined, the eye serves as the means of investigation; but when the ultra- or infra-spectral regions are under consideration, suitable methods of photography must be employed.

When the position of the bands in the absorbent spectra of liquids is to be determined, the light of the sun being taken as the basis for the formation of the absorbent spectrum, it only remains to use a slit of sufficient fineness to produce the solar lines, and thereby obtain the means of measurement. According as they are investigated in different spectra, observations should be taken directly by the eye, or through the agency of photography.

646. Atmospheric Spectrum Lines.—In addition to the fine lines of the solar spectrum to which attention has been directed, there are certain bands and regions of absorption especially evident in the earlier and later portions of the day, when the sun is near the horizon, and when his rays come to us through a greater thickness of the atmosphere. These have been called atmospheric and telluric bands or lines. They originate in the absorptive action of the vapor of water in the earth's atmosphere; but the field has not yet received the cultivation it deserves, and it is probable that, in the future, research will discover other and important explanations of value to the science of meteorology, and, consequently, to medicine.

647. Planetary and Stellar Spectra.—In moons and planets, except Uranus, the spectra are the same as that of the sun, as their light is derived therefrom. In the fixed stars it is not so, their dark lines differing from those of the sun, and from each other. Secchi makes out no less than four types of stellar spectra. "The first embraces the white stars and includes the well-known Sirius and α Lyræ. Their spectra usually contain a number of very fine lines, and always include four broad dark lines which coincide with the bright lines of hydrogen. Out of 346 stars, 164 were found to belong to this type. The second group embraces those having spectra intersected by numerous fine lines like those of our sun. About 140 stars, among them

Pollux, Capella, ϕ Aquilæ, belong to this collection. The third embraces the red and orange stars, such as α Orionis, β Pegasi; the spectra of these are divided into eight or ten parallel columnar clusters of dark and bright bands, increasing in intensity to the red. Group four is made up of small red stars with spectra, and is constructed of three bright zones, increasing in intensity towards the violet. It would thus appear that fixed stars, while differing from one another in the matter of which they are composed, are constructed on the same general plan as our sun, and have a photosphere surrounded by a gaseous atmosphere."

648. Absorbent Spectra by Colored Liquids.—It has been shown that colored flames possess the property of absorbing their own tint of light from the spectrum of an incandescent solid, producing dark lines therein. As might be expected, colored liquids have a similar power, and those which appear colorless also exert a certain absorbent action.

If a solution of *permanganate of potash* in a cell with flat parallel walls is placed immediately in front of the slit of a spectroscope, at the same time that rays from the sun or some incandescent solid are passing into the instrument, the spectrum seen through the telescope presents great bands or gaps, and its length is reduced both in the more and less refrangible regions.

Passing from an inorganic to an organic body, if a solution of *chlorophyl*, the green coloring matter of leaves, be put in the same position, dark bands appear in the red, the yellow, and the violet. In both of these instances the gaps or dark bands are produced by the absorbent action of the fluid, and the fact of their being in a spectrum becomes the evidence of the presence of these fluids in the cell, and an analytical test for the same.

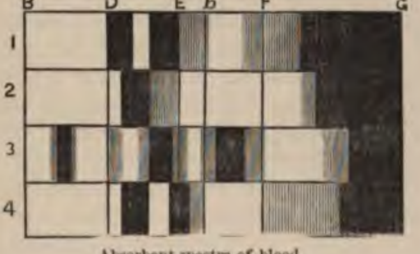
649. Absorbent Spectra by Colorless Liquids.—Russell and Lapraik have made an extensive examination of these spectra. The spectroscope had a single prism of heavy glass. Before the light reached the slit it traversed a column of the liquid from 2 to 8 feet in length. Water gave a band at 600 to 610 of the scale, with a second at 705 to 723. Alcohol one at 630. Methyl, propyl, and amyl alcohols give them nearer to the red as alcohol is higher in the series. Ethyl iodide a second from 716 to 724. Amyl nitrate, acetate, and iodide give bands like that of amyl alcohol, but a little nearer the blue. Chloroform a faint one from 607 to 616, and a strong one from 711 to 717. Aldehyde and acetic acid, large absorption at the red and a faint band. Benzine two, one at 606 to 616, the other from 703 to 714. Phenol two, one near the water band, the other from 679 to

710. Ammonia five, the darkest from 649 to 654, one coinciding with the water, the other with the alcohol band, a narrow sharp one from 566 to 570, and a fifth from 698 to 708. The only liquids which did not give bands were carbon disulphide and tetrachloride. See "Journal of Chem. Soc.," 168, April, 1881.

650. Blood Spectra.—The red coloring substance of the blood discs, called hæmoglobin, presents an absorbent spectrum which varies according as an additional portion of oxygen is associated therewith or not. In the venous blood the discs are of a darker red, and contain hæmoglobin. In their passage through the lungs, an additional portion of oxygen is taken up by their coloring matter; they become a brighter red, the hæmoglobin passing into oxyhæmoglobin. Again, coursing through the systemic circulation the latter is deoxidized, and the former produced. After undergoing these alternating changes a number of times, the hæmoglobin is at last decomposed, and passes into hæmatin, which is also a red colored substance.

All three of these states of the red coloring matter of blood are represented by changes in the absorption spectrum of that substance. The spectrum in each case is given in the following diagrams:

FIG. 286.



Absorbent spectra of blood.

The letters indicate the Fraunhofer lines. The first spectrum represents that obtained from arterial blood, or oxyhæmoglobin. In the second the oxyhæmoglobin is reduced by ammonium sulphide to hæmoglobin. The third shows that given by hæmatin when the solution is acid. The fourth is that of hæmatin reoxidized. It is very nearly the same as that produced by the action of carbon monoxide upon blood. This gas also imparts a bright red tint, which cannot be removed by the same agencies as those which remove the red tint from blood reddened by oxygen.

651. Spectra of Bile and Pettenkoffer's Test.—Certain coloring matters are obtained from bile by the action of strong reagents

which give characteristic spectra. By passing nitrous vapors into bilirubin a body called choletelin is formed, which in acid solution gives a broad band extending from *b* to beyond F. Another product formed in Gmelin's reaction gives in strong solution one from D to *b*. The appearance of this indicates grave disturbance of the system.

The spectrum of Pettenkoffer's test gives a band outside of D, and a broad one at E. Campbell gives the spectrum of sodium taurocholate as three, one between C and D, one between D and E, and a third near F.

652. Other Spectra. Abnormal Spectra.—Certain coloring matters in wine, beer, and ale also give characteristic absorbent spectra.

When a hollow glass prism is filled with indigo solution, potassium permanganate, or alcoholic solution of fuchsine, the distribution of colors is changed. In fuchsine the violet is the least refracted, then the red, and then the yellow, which is refracted the most. Kundt says that all substances with surface color give abnormal spectra.

SECTION VII.

HEAT.

CHAPTER XXIX.

THEORIES AND EFFECTS OF HEAT.

Theories of heat—Sources of heat—Effect of heat on physical properties—Effect on composition—Expansion—Expansion of solids—Expansion of liquids—Maximum density—Expansion of gases—Winds—Effect on measures of time and quantity.

LIFE is possible between the temperatures which determine the fluid state of water. No living creature can survive a heat above 212° F., for the liquid constituents of the body would be dissipated. Certain low germs, however, retain their vitality. None but germs can bear a temperature below 32° F. It is true that a creature may in itself possess the power of generating heat and thus resist low temperatures, but remove this faculty, let the circulating juices of its body fall below 32° F., and unless they are enclosed in capillaries, movement becomes impossible, and death supervenes.

For plants and animals, heat is the all-important condition. Without it the globe would be a dreary, barren waste. The ancient fire worshippers made sacrificial offerings to the sun as the emblematic source of heat and of all earthly good. To the Egyptians a burning torch was the emblem of life.

To the earlier inhabitants of the globe heat meant merely the means of cooking, and the promotion of the comfort of their dwellings. To the modern, it is emblematic of power and a mastery over the earth. Locomotives on land, steamers on the sea, innumerable applications in factories, and those wonderful electro-dynamic engines yielding force and light, are all results of modern applications of heat to generating various kinds of force. Take away the applications of heat which are now so universally employed in giving us the comforts of life, and life

itself would hardly be worth its existence. We may, therefore, profitably employ ourselves with inquiring into the nature of this all-important form of energy.

653. Theories of Heat.—The *first* is the theory of emission, which holds that the molecules of bodies are surrounded by a subtle imponderable fluid, which can pass from one to another. These heat molecules cause repulsion of those of the substance and oppose cohesion.

The *second* is the undulatory theory. As with light, this demands existence of the ether, the molecules of which are in a state of vibration. These motions may be communicated to the molecules of bodies. The hottest bodies are those in which the movements have the greatest velocity and the greatest amplitude. According to this view, heat is a *condition* of matter and not a substance. It is the theory now generally accepted.

654. Sources of Heat.—The *first* is the sun. It is estimated that enough heat is received by the earth from this body each year to melt a layer of ice over 100 feet in thickness. As it only receives the small quantity the passage of which its surface obstructs, we perceive how enormous the amount which escapes into space.

Regarding the source of the sun's heat, various opinions are held. Some maintain that it is the result of mechanical action, arising from attraction of the sun for meteoric matter floating in space, which, when it comes within the range of the sun's action, is drawn into that body, and the temperature is sustained by the continuous pelting of this matter striking the sun with inconceivable velocity.

Another theory, held for some time, was that of combustion, but there is nothing to show that this is true. It is generally maintained that oxygen does not exist in the sun, but I have demonstrated that the spectrum of that body shows exceedingly fine lines, which correspond with those of the bright spectrum of oxygen, "American Journal of Science and Arts," Oct. 1878, and June, 1879 (443). Granting that oxygen does exist in the solar envelope, it has nothing to do with its heat, since at the temperature which prevails compounds cannot form. The elements all exist in their elementary state; and if compounds could be formed in one locality they would instantly be dissociated by the surrounding intense heat.

Helmholtz maintains that the smallness of the sun's density, only one-quarter that of the earth, suffices to explain the origin of the high temperature. Assuming that slow contraction is going on, he estimates that a shrinkage equivalent to $\frac{1}{10000}$th of

the sun's diameter would evolve as much heat as has been emitted from that luminary during 2100 years (444).

The *second* is the internal heat of the earth. Shafts which have been sunk in the earth's crust show a uniform elevation of temperature with increase of depth. The rate varies in different parts, but may be stated as 1° F. for every 50 to 100 feet. At a depth of 30 feet all evidence of seasonal change is lost, and a regular increase of temperature is established. At this rate, it is estimated that within a distance of 50 miles from the surface everything, even the most refractory, is in a molten state. Geological considerations also tend to show that a section of the earth would be represented by an external solid zone 30 to 50 miles thick, then one of liquid matter of unknown depth, then a core or nucleus of solid matter. As we descend, the melting point would under the enormous pressure become so high, that it could not be maintained in that state.

The *third* is chemical action of all kinds. Every process of oxidation, whether a rapid combustion or a slow rusting, every act of fermentation, putrefaction, or decomposition, evolves more or less of this form of energy.

The *fourth* is mechanical action, as friction of all kinds. By blows or percussion a blacksmith may make a small portion of iron red-hot. A bullet discharged against an iron target melts by the sudden arrest of its movement. Indeed, heat is the final form of energy to which all other forms tend, and in which they will all be finally dissipated.

Fifth, electric action, as when a current of voltaic electricity is forced to pass along a narrow conductor; a principle which has recently been utilized in the incandescent carbon or platinum light of Edison.

655. Effect of Heat on Physical Properties.—The form of a substance is absolutely dependent on its temperature. Water, for example, below 32° F., is a solid, between that and 212° F. a liquid, above 212° F. a vapor. In Fig. 287 we give some of its crystalline forms assumed as it passes into the solid state; the hexagonal predominates. All solids become liquids under a sufficient elevation of temperature.

Color also is dependent on temperature. The iodide of starch, prepared by adding a little tincture of iodine to a solution of starch, is of a rich dark-blue hue, raise its temperature nearly to the boiling point, and it becomes colorless. Cool it, and the blue tint is restored. So also red iodide of mercury sublimes yellow; white oxide of zinc heated turns yellow, and a host of other bodies, if submitted to a change of temperature, show change in color.

Size is controlled by temperature. If we take a copper sphere and fit it accurately to a ring so that it just passes through when cold, and then raise its temperature, it fails to

FIG. 287.

Ice flowers.

pass. It has swollen or undergone expansion by the action of heat. Cool it, and it passes. Fig. 1.

From this experiment we perceive that heat expands a body, and loss of heat, diminution of temperature, or cold, causes it to contract. *Its size is absolutely dependent upon its temperature.*

656. Effect on Composition.—If oxide of mercury be placed in a test-tube and submitted to a sufficiently high temperature it

undergoes decomposition, oxygen being set free, and mercury subliming in minute globules on the walls of the tube. This separation of a compound into its elements by action of heat is called *dissociation.*

While a few inorganic bodies undergo dissociation below 1000° F., there is no organic substance which can resist that temperature.

A portion of wood, starch, muscle, or other organic body, placed in a tube and heated, soon begins to undergo change, gases are discharged, and water is given off, various volatile fluids with either a pleasant or an unpleasant odor escape, and a residue of black carbon remains. Heated on platinum in the air, such bodies catch fire and burn, a charred mass of carbon remaining for a time, which by continued application of heat is finally oxidized, and a white ash obtained. Heat, therefore, is the test for differentiation between an inorganic and an organic body, especially when used in connection with air. The black residue of carbon which arises, and which is completely oxidized by prolonged application of a high temperature, proving the substance to be organic.

In addition, heat determines whether the organic body is nitrogenized or not. If during the combustion the fumes do not have an odor resembling that of burning hair, the absence of nitrogen may be inferred. If, on the contrary, this odor is perceived nitrogen is present, and we are dealing with a nitrogenized substance.

657. Expansion.—In the experiment of the ball and ring (655) it was found that temperature governs the size of a solid; it remains to examine its effect on other forms of matter.

Take a flask, A, Fig. 288, with a long neck, and place in it some colored alcohol, or any other fluid, mark on the neck its position, and then apply heat to the bulb. As the temperature augments the liquid rises in the neck, showing that it has undergone expansion. We also find that this is far greater than with the solid, when we were obliged to resort to the use of delicate means of measurement to demonstrate that there was an increase. Now remove the flame, contraction begins and, with return of the original temperature, the normal size is gained.

Fig. 288.

Expansion of liquid and gas.

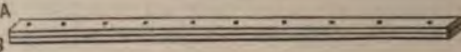
Gases also follow this law, as illustrated by placing a flask, B, with the mouth of its neck under water, and adjusting, so that the level of the fluid is half-way up the stem, and the rest filled with air. Apply a flame to the bulb, the merest touch suffices to cause an

instant expansion of the included air, and if we are not careful some of it will escape from the vessel. With return to its former temperature the original size is gained.

All forms of matter, therefore, solid, liquid, and gas, are expanded by increase of temperature, and contract when it decreases. For the three forms we also learn that for solids the expansion is small, for liquids greater, and for gases the greatest of all.

658. Expansion among Solids.—Take a thin strip of iron, A, and a similar one of brass, B, about three feet in length, and half an inch broad. Rivet them firmly together, so that at ordinary temperatures the compound bar is straight. Fix one

FIG. 289.



Expansion compound bar.

end of this in a vice, and allow the other to play over a scale. If heat is then applied to its under side, the free end at once begins to traverse the scale. Remove the heat and it moves in the opposite direction.

From this we perceive that there has been a difference in the rate of expansion in the metals by the application of heat, as shown by the curvature produced in the apparatus. The metal which expands the most is that on the outside of the curve. In this experiment it is the brass. When the original temperature is gained the bar is again straight, but as we pass beyond that to a lower, curvature in the opposite direction takes place, the metal contracting, the most being on the inside, and we again find it is the brass.

Brass and iron, therefore, have very different rates of expansion for the same elevation of temperature, and it may be said that no two solids expand exactly the same for a given rise of temperature.

Coefficients of linear expansion of solids between 0° *and* 100° *C.*

Pine, 0.000003000	Tin, 0.000021730
Marble, 0.000008490	Lead, 0.000028575
Cast iron, 0.000011250	Zinc, 0.000029417
Copper and brass, 0 000017182	Sulphur, 0.000064130
Silver, 0.000019097	Paraffine, 0.000278540

The coefficient of linear expansion is the elongation of the unit of length when the temperature rises from 0° to 1° C.

The coefficient of surface expansion multiplied by three gives that of cubical expansion.

Numerous instances of this are seen on all sides. Telegraph wires sway lower as the temperature rises. Steam pipes in houses must be arranged to allow play for their expansion, or they quickly get out of order and leak. In the Brooklyn bridge the vertical movement in the centre owing to variations in temperature amounts to several feet.

Sometimes this expansion and contraction of rods of metal is employed to bring the walls of buildings out of plumb into a straight line. A series of rods are passed through the walls, each having a screw head at one end. Alternate ones are then heated by spirit flames, they expand, the screws are brought up tight, and they cool. Their contraction draws the walls up a little. The other set is then heated and the slack taken up; as they cool they bring the walls a little more together. This is continued until they are brought to the vertical and properly secured.

Where a substance is a poor conductor, as glass, heat does not permeate quickly if it is thick. By the unequal expansion which follows, fracture takes place from the strain put upon the molecules. At the same time if it is very thin, as in flasks and retorts, and properly annealed, they will bear contact of the hottest Bunsen flames while filled with cold water.

Fig. 290.

Difference in expansion of liquids.

659. Expansion among Liquids.—In liquids great differences in expansion are found. To demonstrate this take two bulbs with long tubes as nearly alike as possible as regards diameter of bulb and calibre of tube. Fill one, A, with alcohol, and the other, W, with water to the same level, and immerse them in a vessel, V, containing water at a temperature of 140° F. Expansion will immediately begin, but the former will rise more rapidly than the latter and attain a considerably higher level. As they cool the alcohol will contract more rapidly, until original temperature and size are gained, and they stand at the same level.

Liquids, therefore, expand differently, their rates being as follows:

Coefficient of expansion of liquids between 1° and 100° C.

Mercury	0.01543	Nitric acid	0.11
Water	0.0466	Alcohol	0.116
Sulphuric acid	0.06	Bisulphide of carbon	0.125
Ether	0.06	Chloroform	0.157

660. Maximum Density.—Water and certain other fluids do not expand uniformly, but as they approach their boiling and solidifying points begin to move in an irregular manner. Especially is this the case with water. If we begin to mark its manner of contraction at 60° F. or thereabouts, we find that as the temperature diminishes it contracts in a uniform and orderly manner for each degree of descent until it reaches 45°, then irregularities appear. When 4° Cent. or 39° F. is reached, contraction ceases, expansion sets in and continues to the freezing point. At 4° C. or 39° F. water is in its most compact or condensed condition, whether heated or cooled it expands. It is, therefore, said to be in the state of maximum density.

Other fluids which have this property are cast-iron, and preeminently, type metal. It is this which enables the latter alloy to copy the fine lines of a mould so accurately. Sulphur also expands as its point of solidification is approached, and can, therefore, be used in the preparation of casts of medals.

661. Expansion of Gases.—While the rates of expansion for solids and liquids show great variation among themselves, it is very different with gases. Here the great tenuity of the substances brings them nearer in relation to each other, and but slight variations are perceptible. Indeed, in an ordinary course of experimentation they are not visible, and require great care and exact means of measurement for their determination. We, therefore, say that for gases the rate of expansion is very nearly the same, being about $\frac{1}{491}$ of their volume at 32° F. for every degree F. of temperature above that point.

Coefficient of expansion of gases between 1° *and* 100° *C., for a single degree.*

Air	0.003667	Nitrous oxide	0.003719
Hydrogen	0.003661	Cyanogen	0.003877
Carbon dioxide	0.003710	Sulphurous acid	0.003903

A practical application of the expansion of air is made in the Ericsson engine. In this arrangement a small quantity is forced into a fire, where it maintains the combustion. In its expanded condition, as product of oxidation, it is employed to work a piston in a cylinder and produce motion.

662. Winds.—By the action of heat great waves of air, called winds, are initiated in the atmosphere. In their formation a portion of the earth is heated. The air expands and an upward movement is produced. Under these circumstances the surrounding air flows into the vacant space and a wind is established. It is clear that it takes its origin in, and blows toward the place where the upward current originated. It would, therefore, be proper in the case of a wind to speak of it in

reference to the point to which it is tending, and not to that from which it is coming.

Their character is best seen on ocean islands. During the day, from eight in the morning to three in the afternoon the land is warmer than the sea, and the wind sets from the latter, it then dies away, and at sunset springs up from the opposite direction, giving a sea breeze by day and a land breeze by night.

In the Indian Ocean the monsoons, which are semi-annual alternations, are produced in a similar manner. The trade winds which blow continuously in the same direction on each side of the equator, result from the ascensional property and from the earth's rotation. Between them there is a zone 5° or 6° wide, where calms and variable winds prevail.

While at the surface of the earth the wind is setting towards the equator, in the upper regions it is moving towards the poles. At the former, rotation of the earth causes the air to drag. In the latter, it is moving more rapidly than the earth as it tends towards polar regions. Thus easting and westing are given to what would be north and south currents if the earth was at rest. In the northern hemisphere the movement is towards the right of a person travelling with the wind; in the southern, towards the left.

A west wind has an excess of centrifugal force which tends to carry it towards the equator. An east wind has a tendency towards the poles. In the northern hemisphere the deviation is to the right, in the southern to the left. If in the former, there is a sudden diminution of pressure over a considerable area, the surrounding air moves toward it. The converging streams before they meet are deviated to the right, and thus cause an eddy or cyclone.

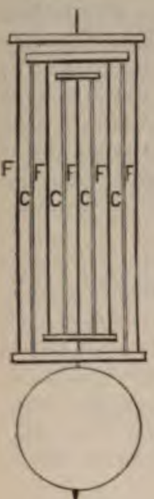
Instruments called *anemometers* are used for the measurement of the velocity of winds. They are four hollow half hemispheres set at the extremities of two diameters of a circle and mounted on an axis. The wind causes the apparatus to rotate, when its rate is measured by clockwork attached to the axis. In this instrument the centre of each cup moves with a rapidity one-third that of the wind. The velocity of the cup, therefore, being known, that of the wind is easily estimated.

663. Effect on Measures of Time and Quantity.—The measurement of time is accomplished by the beat of a pendulum in a clock, or the oscillations of a balance wheel in a watch. For these to beat true time the length of the pendulum rod, or diameter of the balance wheel, must be invariable. With ordinary clocks and watches no care is taken, but in finer instruments it is accomplished by the following devices.

1st. The gridiron pendulum, Fig. 291, so called because it

consists of nine parallel rods, which give it a fancied resemblance to that domestic implement. Four of these are copper, C,

Fig. 291.



Gridiron pendulum.

Fig. 292.

Compensation strips.

Fig. 293.

Mercurial pendulum.

and five iron, F. They are arranged to have the latter expand downwards from an upper fixed support, while the former expand upwards from a lower one. The centre of oscillation is thus kept at the same distance from that of suspension, and the pendulum beats uniformly.

2d. Compensation strips, Fig. 292, consist of a compound bar of brass and iron, 1, fitted at right angles to the rod of the pendulum near the bob, and bearing small spheres at their extremities. The size of these and the length of rod are properly proportioned to that of the bob. The brass of the compensation bar being placed downwards, when the temperature rises the balls at its extremities are raised, as at 2, while the bob of the pendulum is lowered. On cooling, the reverse takes place, as at 3. The centre of oscillation is thus kept invariable and the pendulum beats true time.

3d. Mercurial pendulum. In this the bob is a jar or jars of mercury, fitted in a stirrup at the end of the pendulum rod, Fig. 293. As the latter expands and tends to lower the centre of oscillation, the mercury by its expansion in the opposite direction raises it, and the balance is preserved.

4th. Compound balance wheel. The circumference of the balance wheel of the watch is divided into two semi-circumferences, both compound bars. One end of each is fitted to a diameter of the wheel, the other is free.

It bears a weight consisting of screws. As the temperature varies the position of the screw heads changes, making the centre of oscillation of the wheel invariable, and it beats true time.

All measures of quantity are subject to variations in their dimensions as their temperature changes. To obviate this, that at which it is taken should always be given. English measures, particularly those of capacity, are generally graduated either at 60° or 62° F., the average heat at which they are employed. The best method is to make the scale at this standard; it may be taken at any degree, and the proper correction for change in volume of the vessel and the fluid or gas made.

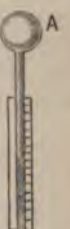
CHAPTER XXX.

MEASUREMENT OF HEAT.

Sanctorio's thermometer—Differential thermometer—Liquid thermometers—Calibering the tube—Preparing and filling—Graduation of the thermometer—The scale—Medical thermometers—Registering thermometer—Displacement of zero—Absolute zero—Remarkable temperatures—Pyrometers—Breguet's thermometer—What thermometers measure.

664. Sanctorio's Thermometer.—Expand a bulb, A, on the end of a tube, place the latter with its mouth permanently under the surface of colored liquid, B. Expand the air in the former by heat and expel a portion of it through the fluid. When the bulb cools the fluid will rise in the tube, and form an air or Sanctorio's thermometer. The slightest breath of warm air causes the index liquid to move downward, the least application of cold produces action in the opposite direction. It is a most delicate thermometer. The difficulty with it is, that it also indicates the slightest variation in pressure.

FIG. 294.



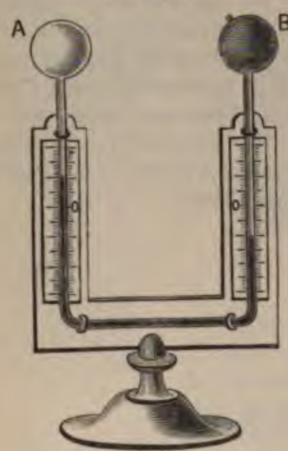
Sanctorio's thermometer.

Place the instrument under an air-pump bell and proceed to exhaust, the least action of the pump produces movement in the liquid, and to a far greater extent than that caused by heat.

The sudden elevation and depression of the apparatus will also cause considerable change in the index fluid. In its original and simple form the air thermometer is not reliable as a heat measurer.

665. Differential Thermometer.—Take two bulbs, A B, and having introduced some liquid into one, cement them together and bend the tube twice at right angles, to bring the bulbs opposite each other, Fig. 295. Now blacken B and we have a differential thermometer, or one which measures the differences in temperature between its bulbs. The slightest breath of warm air on B causes the index fluid to pass away from it towards A. A little cold water applied to B produces movement in the opposite direction. Place the instrument under an air-pump bell, and the liquid index is not affected by the most complete exhaustion. Though limited to determination of differences in the temperatures of its bulbs, it is most satisfactory and reliable when it can be employed.

FIG. 295.



Differential thermometer.

666. Liquid Thermometers.—Practically, these are confined to mercury and alcohol. The great advantage in the former is that it moves in a cleanly way in the tube, does not adhere to or soil it, and gives very accurate indications. Its high boiling point, and low temperature required for solidification (a range from about 660° F. to nearly —40° F.), and its rapid movement, fit it admirably for this purpose.

Where temperatures lower than —40° F. are to be measured, colored alcohol is employed. This boils at about 176° F., and does not solidify until —220° F. is reached; even at this point it can hardly be called solid. It soils or wets the wall of the tube; therefore, considerable time should be permitted for it to gain its true level when it has fallen, before an exact reading can be made.

667. Calibering the Tube.—By this we understand that all parts of the tube are to be proved to have the same diameter. For an alcoholic thermometer the bore must be circular, for the mercurial it may be either circular or elliptical. The advantages of the latter are that a very small quantity of mercury may be made to give degrees of considerable size in a bore the diameter of which in one direction may be six to ten times that of the diameter at right angles to it.

Having selected the tube, it is calibered by placing in it a column of mercury one inch in length, the measurement being

made by a pair of compasses. The column is then traversed to another position, and its length measured. In this way all parts are examined, and if the mercury is of the same dimensions throughout, the caliber is uniform, and it will answer. If, on the contrary, it varies ever so little, it is useless.

668. Preparing and Filling.—The tube is drawn off in the blowpipe flame, and the extremity closed. It is also elongated at the other end to a suitable length. The sealed portion is then heated in the blowpipe flame and air quickly forced in through the open end. After two or three trials a uniform bulb is expanded, and the apparatus being allowed to cool, is ready for the liquid.

The bulb being gently warmed, to expand the air contained therein, the open end is quickly placed under the surface of fluid. As it cools the latter gradually rises, and a small quantity gains access to the bulb. This is heated until it boils, and the bulb and tube are filled with vapor. The mouth is then again immersed in the liquid, when as the vapor condenses the fluid rises, filling the tube and bulb. This process may be facilitated by expanding a small funnel in the top of the former and filling it with clean dry mercury. It may then be kept in the vertical position throughout the operation.

The extremity is now to be closed. To accomplish this the bulb is heated, the fluid expands and escapes from the open end; when the boiling point is nearly attained the lamp is removed, a blowpipe flame directed on the pointed end, and the glass fused. Communication with the external air is thus destroyed. The instrument should then be put aside for some months before the scale is adapted, since a certain amount of shrinkage of the bulb is apt to occur.

669. Graduation of the Thermometer.—There are two fixed points on all thermometric scales. The lower is the melting of ice, the upper the boiling of water. It will not answer to make the former the freezing of water, for this is a variable point, and, therefore, unreliable. It is determined by tying a thread around the tube, and then placing the entire instrument in a tall jar filled with cracked ice and water; the thread is from time to time adjusted as the liquid falls, and when the final adjustment is attained, a delicate mark is made with a triangular file or diamond. The higher point is then fixed by placing another thread around the tube and immersing it in a flask half full of water, until it nearly touches the fluid. The mouth should be lightly closed with a plug of cotton. When the water is boiling strongly, and the flask filled with clear steam, the thread around the tube is adjusted, and a mark permanently

made as the higher fixed point. The barometer should indicate 760 millimeters. A difference of 27 millimeters in pressure would make a variation of one degree in graduation.

670. The Scale.—Of these there are three, Fahrenheit, Centigrade or Celsius, and Réaumur's. Each possesses certain advantages. In the first the degrees are small, there being 180 between the two fixed points. The lower is 32°, and there is a considerable march beyond this before zero is reached, and the use of minus (—) quantities becomes necessary. The Celsius, on the contrary, has large degrees, nearly twice the size of the former, and fractions are often necessary in expressing ordinary temperatures. The use of the — sign as soon as the freezing point is passed often leads to error by its omission. The division is more scientific, however, and of the centesimal character towards which all modern methods of measurement tend. Yet it does not appear to force its way with English-speaking people, and it will doubtless be some time before our thermometric readings are given in this scale. The third, or Réaumur's, has 80 degrees between the two fixed points. It presents all the disadvantages of the Centigrade, and none of its advantages.

In adapting the scale to the thermometer, if the Fahrenheit is used, the space between the two fixed points is divided into 180°. To the lower the value 32° is given, to the upper 212°, and the graduation is extended above and below. In the Centigrade, 0° is given to the lower, and 100° to the upper; in the Réaumur, 0° to the lower, and 80° to the upper.

The best plan is to mark the scale directly on the tube, either with a diamond or by etching with hydrofluoric acid. Other methods are, however, employed, ivory, bone, paper, metal, all bear the graduation in common instruments, and answer very well.

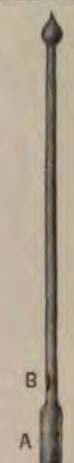
For conversion of Fahrenheit into Centigrade the formula is: $\text{F.} = \frac{\text{C.} \times 9}{5} + 32° \text{ F.}$ For the opposite, $\text{C.} = \frac{\text{F.} - 32 \times 5}{9}$. A simple and rapid formula for conversion of C. into F. is: Double the degree Centigrade given, subtract $\frac{1}{10}$th of the product, and add 32°.

In alcoholic thermometers the lower fixed point is determined as stated. The upper, by comparison with a good mercurial thermometer.

671. Medical Thermometers.—The recent demands of medicine have caused the construction of thermometers in which fractions of a degree can be easily indicated in the vicinity of 94° F., and the column of mercury *held at the point* to which it has risen. In these the bulb is made cylindrical, A, and the lower part of

the tube contracted, B. The movement of the fluid past this when expanding is not interfered with, but when contraction begins, the column breaks, and the thermometer indicates the highest temperature it has reached. When the instrument is used again the broken column is united by a slinging motion of the hand, bringing centrifugal force into play. The movement is repeated two or three times, until the purpose is attained. For accuracy, such thermometers should be retained in their position for three to five minutes, to allow the mercury time to gain its true place.

FIG. 296.



Medical thermometer.

These, and others which accompany urinometers, are often graduated only to 120°, or thereabouts. Care must be taken not to immerse them in liquids of a higher temperature, or they will be destroyed.

672. Registering Thermometers.—These are used for meteorological purposes. They are known as maximum and minimum thermometers. They consist of two, a mercurial for high, and an alcoholic for low temperatures. The column of mercury in the first may be broken by the preceding device of a capillary tube, as in the Negretti, or it may push a delicate index before it which it leaves at the highest it reaches, thus registering the upper temperature. The alcoholic instrument carries an index in the fluid. When expansion takes place the latter passes the former, but in the opposite movement the former is drawn by the latter and remains where it is carried, the fluid passing it when it again expands, thus the low temperature is marked. The index usually contains a piece of iron wire, and can be adjusted by a small magnet accompanying the instrument.

673. Displacement of the Zero.—Thermometers used for a long time often show a change in position of the zero. In describing their construction, it was stated, that as perfect a vacuum as possible is made over the fluid to prevent introduction of dust, loss by evaporation, and to allow the column to be broken when desired. It, therefore, follows that they must bear the full pressure of air, viz., 15 pounds on every square inch. Under this the delicate film of glass forming the bulb yields, and after a time a change of two or more degrees will be found in the position of zero. Allowance must be made for this in all readings.

673 A. Absolute Zero.—Air expands $\frac{1}{491}$ of its volume for every degree F. we give it above 43° F., or $\frac{1}{273}$ for every degree C.

above 0° C. It, therefore, follows that the lowest temperature we could express by an air thermometer would be —459° F. or —273°C. These values are called the absolute zeros, and temperatures estimated from them are called *absolute.*

674. Remarkable Temperatures.—The following are taken from Ganot's "Physics." They are in Centigrade values.

	Centigrade.
Greatest artificial cold produced by a bath of bisulphide of carbon and liquid nitrous acid	—140°
Greatest cold produced by ether and liquid carbonic acid	—110°
Greatest natural cold recorded in Arctic expeditions	—58.7°
Mercury freezes	—39.4°
Mixture of snow and salt	—20°
Ice melts	0°
Greatest density of water	+4°
Mean temperature of London	9.9°
Blood heat	36.6°
Water boils	100°
Mercury boils	350°
Sulphur boils	440°
Red heat (just visible) (Daniell)	526°
Silver melts "	1000°
Zinc boils "	1040°
Cast-iron melts. "	1530°
Highest heat of wind furnace (Daniell)	1800°

675. Pyrometers.—The first of these was the invention of Wedgewood, the porcelain manufacturer. It consisted of two inclined bars fitted firmly into a base, nearer together below than above. One of these bore a scale. Portions of porcelain clay were moulded, dried, and fitted to the upper or widest division. It was then submitted to heat, and when cool, again placed in the apparatus, when the shrinkage showed the temperature to which it had been subjected; thus the melting point of various metals was determined. It was, however, found that clay acts peculiarly under the influence of heat, a low degree applied for a long time producing as much shrinkage as a high temperature applied for a brief period; time is, therefore, an important element, and not to be overlooked, otherwise grave errors will arise.

Another form consists of a rod of brass or steel, its expansion being measured by means of multiplying machinery consisting of levers or cogs and wheels. All these are of little or no value on account of their irregular movements.

676. Breguet's Thermometer is, in fact, a compound bar consisting of a slim strip of platinum soldered to one of silver, and rolled down to the hundredth of an inch in thickness. From this, slips about $\frac{1}{20}$th of an inch wide are cut, their length being 10 or 20 inches. One is wound into a spiral, A B, which is fixed

at one end, A, and free to move at the other. The latter bears an index, B, which traverses a graduated circle bearing degrees similar to and of equal value with the Centigrade scale. This form is exceedingly delicate. The gentlest breath on the spiral suffices at once to carry the index to the temperature of the expired air. It loses its heat as quickly, and returns to the original degree. It is curious that the Breguet has not been adopted in medical practice, when it is so admirably fitted to yield the indications sought by the physician.

FIG. 297.

Breguet's thermometer.

677. What Thermometers Measure.—If we take a series of vessels of increasing size and fill them with water from the same source, and then place a thermometer in each in succession, it marks the same degree. Yet we know that the largest vessel contains as much more heat than the smallest, as its size is greater. From this we perceive that the thermometer does not measure the quantity of heat in a given mass. It merely *indicates the temperature intensity or the degree of heat.* The quantity is to be determined in other ways.

CHAPTER XXXI.

SPECIFIC HEAT AND HEAT OF FORM.

Heat required to warm a substance—The calorimeter—Determination of specific heat—Calorie and thermal unit—Fusion and solidification—Variation in fusion and solidification—Change of volume in fusing—Annealing—Latent heat—Latent heat and climate—Freezing mixtures—Crystallization.

678. Heat Required to Warm a Substance.—If we take equal volumes of mercury and water and place them in front of a fire, the temperature of the former rises much more rapidly than that of the latter. If we use the same weights of the two substances the difference is far more striking. From this we learn that *different bodies require different quantities of heat to warm them equally.*

In solids the same thing is evident. Take bullets of zinc and lead, and warm them equally by exposure to boiling water,

giving them time to take up all the heat they will. Then drop them on a slab of wax, about half an inch thick. The zinc melts its way through very quickly. The lead follows at a considerable interval. The heat held by the former was greater than that of the latter.

To this the name of specific heat, or capacity for heat, is given. *By it we mean the amount of heat required to raise the temperature of a substance one degree compared with that required to raise the temperature of the same weight of water one degree.*

If, therefore, it is stated that the specific heat of lead is 0.0314° C., it means that the quantity which would raise the temperature of a given weight of lead one degree C., would only raise that of the same weight of water 0.0314° C. In all instances the comparison is with water.

By the sudden compression of a gas the specific heat or caloric diffused throughout, say 100 cubic inches, may suddenly be forced into one cubic inch. The temperature will, therefore, be increased one hundred-fold, for a mere instant of time. An illustration is offered by the fire-syringe, in which the piston is armed with black tinder; the lower part of the cylinder is closed. The latter being filled with air, the former is introduced and suddenly driven to the bottom, the heat developed by compression of the air is so great that the tinder catches fire, and a flash of light is seen. Here we have a beautiful illustration of the conversion of work into heat. The force applied to the piston is not lost, but converted into heat. If we instantly release the compression before this has had time to be conducted away, it disappears in the expansion of the gas to reach its original volume. It is reconverted into work represented by the restoration of the piston to its original position.

Three methods are used for the determination of specific heats: 1st, by the calorimeter or melting of ice; 2d, by mixtures; 3d, by cooling.

679. The Calorimeter, in its simplest form, consists of a block of ice with a cavity hollowed out in the interior, the mouth of which is closed by a slab of the same material accurately fitted. The object of the experiment, a liquid, is placed in a thin flask, its weight accurately determined, and its temperature carefully noted. The cavity is then emptied of any water it may contain, the flask placed therein, and the mouth instantly closed. The temperature of the flask and contents at once begins to fall, and in so doing melts the ice. When the process is completed the flask is removed from the cavity, the water produced by melting is carefully measured or weighed;

FIG. 298.

Ice calorimeter.

this indicates the amount of heat contained in the substance under examination. By a simple calculation the quantity for each degree, F. or C., is estimated.

If great accuracy is required, a correction must be made for the glass of the flask by repeating the operation with it alone. It is also better to use a sponge to remove the fluid from the cavity, weighing it before and after the operation, the difference in weight represents the quantity of water.

The difficulty in obtaining blocks of ice of sufficient size and compactness, led to the introduction of the calorimeter of Lavoisier, in which ice is placed in a vessel surrounded by a jacket also filled with ice. The exterior layer in the jacket protected the interior from the action of air. The water resulting from the experiment is drawn off by faucets.

680. Determination of Specific Heat.—A given weight of water is first placed in a flask in the calorimeter, its temperature taken, and the amount of fluid it produces by melting carefully determined. The quantity for each degree is calculated. An equal weight of the substance to be examined is then placed in the flask, its temperature taken, and the quantity of liquid it can form determined, and that for each degree estimated. This is compared with the result obtained in the first experiment, when a simple calculation gives the specific heat of the second body, water being 1.

In the method by mixtures, the temperature of a given weight of the body is raised to a certain point, it is then immersed in a mass of water of known weight and degree. From the temperature of the water after mixture, the specific heat of the body is calculated.

The method by cooling consists in the determination of the relative times required by given weights of different bodies to cool through a certain number of degrees.

A knowledge of specific heat is of considerable importance in the determination of the atomic weights of elementary bodies.

681. Calorie and Thermal Unit, etc.—*A calorie is the quantity of heat required to raise one kilogramme of water through one degree Centigrade. A thermal unit is the quantity of heat required to raise one pound of water through one degree Centigrade.*

One calorie = 2.2 *thermal units. One thermal unit* = 0.45 *calorie.*

The other heat units employed are the *gramme-degree, or the quantity of caloric required to raise one gramme of water one degree C.*

The pound-degree, the caloric required to raise one pound avoirdupois of water one degree F. or C.

The foot-degree, the caloric required to raise one cubic foot of water one degree F. or C.

682. Fusion and Solidification.—The first effect of heat on a solid is to cause expansion, this continues for a certain time, when the body liquefies; to this the name of fusion is given. The laws are as follows.

1st *Law.* A given solid begins to melt with few exceptions, easily explained, at a fixed temperature. This is called its point of fusion. It is a specific character of the substance. The range for solids is very great, as shown in the following table:

	Centigrade.		Centigrade.
Carbonic acid	—78°	Tin	228°
Mercury	—40°	Lead	332°
Ice	0°	Silver	1000°
Phosphorus	44.2°	Gold	1200°
Wax	64°	Iron	1500°
Sulphur	115°	Platinum	2000°

2d *Law.* During fusion the temperature of a body remains fixed, that of the fluid rises in spite of the most active stirring.

Solidification. When a liquid is cooled it contracts and finally assumes the solid state, under the law that a liquid begins to solidify at the same degree at which the solid begins to melt. In other words, the solidification and the fusion point are, as a rule, the same.

683. Variation in Fusion and Solidification Points.—If water is kept perfectly still the temperature may be carried considerably below 32° F. without the assumption of the solid state, and it may be lowered to 0° F. If it is then touched, or the slightest agitation communicated to it, a portion instantly solidifies and the temperature rises to 32° F. Though it may be cooled below 32° F. without freezing, by no device can ice be warmed above that degree without melting. Melting of ice is, therefore, taken as the lower fixed point on the thermometric scale.

Under great pressures water retains its fluidity below 32° F. Broken ice may be compressed into lenticular, cylindrical, and other forms. This is what is known as regelation, a term introduced by Tyndall in explanation of the plastic nature of ice in glaciers.

684. Change of Volume in Fusing.—When a substance enters into fusion there is generally a rapid expansion. In a few instances, however, the reverse happens. Of all bodies the most notable exception is water; in the act of fusion it shrinks greatly, losing no less than one-ninth of its volume.

In solidification the reverse occurs, passing into the state of ice it expands. The increase in bulk is about one-ninth, hence it is that ice floats, and forms on the surface.

This fact exerts a most important influence on climate. By virtue of it ice forms on the surface of ponds, rivers, lakes, and by its con-conducting power cuts off further loss of heat from the water beneath. In the spring it is most favorably exposed to the action of the sun's rays, and in the best position for being melted. We can hardly realize the difficulties that would arise were it not for its maximum density, and its sudden expansion as water assumes the solid state. Rivers and all collections would congeal from below. They would solidify throughout, and a long period of time would be consumed in the spring in melting the gigantic accumulations of winter ice.

685. Annealing.—In passing to a solid from a liquid state the molecules of bodies must have time to adjust themselves to the new conditions presented. Especially is this the case with most metals, and with glass. The process of annealing consists in a gradual depression of temperature, and the allowance of a sufficient time for this adjustment to take place at least in a partial manner. Glass which has been suddenly chilled is exceedingly prone to fly in pieces if touched by a point or scratched; of this the Prince Rupert drops are an example. The larger the mass the greater the difficulty in annealing it. The iron cylinders of great marine engines require weeks for the accomplishment of this process. In glass works it is an essential part of the manufacture, and the value of an article and its power to withstand rough usage depend entirely on the care with which it has been annealed. By recent devices, the so-called *malleable glass*, which will bear the roughest usage, is prepared. Pieces of it may be thrown violently on the floor without undergoing fracture.

686. Latent Heat.—If a pound of water at 80° C. be mingled with a pound at 0° C., the temperature of the mixture will be 40°, or the average of the two. If in place of the latter a pound of ice is used, it will be 0° C. We, therefore, perceive that the sensible heat of the water has been lost in melting the ice; in other words, it has become latent or hidden. *Latent heat, therefore, is that heat which disappears when a substance changes its form. It is the heat of form.*

To determine exactly how much heat is lost, take a mass of ice at 32° F., and arrange to have it warmed at the rate of one degree F. per minute. At the end of ten minutes it has risen 10°, and it steadily rises until 32° F. is reached. Here it stops and begins to melt. This continues for 140 minutes, at the end of which the march of temperature recommences. During this 140 minutes the ice received one degree of heat per

minute, which was rendered latent, and consumed in changing water from solid to liquid. It is evident that this 140° F. represents the caloric of fluidity or the latent heat of the liquid.

Again continue the application of heat, and the rise of temperature continues steadily at the rate of one degree per minute until 212° F. is reached, it then stops, and the water begins to boil. Place a thermometer in the boiling liquid, it registers 212° F.; place it in the steam rising therefrom, again it marks 212° F.; both have the same temperature. At the close of 1000 minutes the water has disappeared as steam, and has carried off 1000° F. of heat in the latent form; we say, therefore, that the latent heat of steam is 1000° F.

687. Latent Heat and Climate.—The loss of latent heat before it can assume the solid state, has its influence in moderating the climate of regions in the vicinity of collections of water. The 140° F. of caloric which it must surrender suffice for a long time to resist reduction of temperature, and in the vicinity of great water surfaces sudden changes are the exception and not the rule. The variations by which the thermometer indicates a cold of —40° F., or a summer heat of over 100° F., belong to regions at a distance from the shore.

Between New York and the immediate coast a difference of five and often ten degrees is experienced in very cold weather. This is owing to the fact that, while land easily reaches a temperature below freezing, water, when 32° F. is reached, surrenders its caloric of fluidity, and resists the tendency to a further depression.

Elevation of temperature is, in like manner, retarded, for ice must have its caloric of fluidity before it can assume the liquid form. By its demand for latent heat water tends to regulate temperature, resisting sudden movements in either direction above or below the freezing point.

688. Freezing Mixtures are forced fusions in which one substance is compelled to melt by the action of some other, as salt and ice. Salt attracts water and forces it to assume the liquid state. To accomplish this the ice must have its caloric of fluidity, and it takes it from any substance in its vicinity, reducing the temperature nearly to 0° F. Here, however, action ceases, and the water rejecting the salt with which it had combined reassumes the solid state if subjected to a further diminution of temperature.

689. Crystallization.—Where bodies pass slowly from the liquid to the solid state they tend to assume special geometrical forms,

e. g., cube, prism, etc. These are called crystals. The process may take place either from a fused condition of the substance, or by evaporation of a solution in water. In the former it is said to be by the *dry way*, in the latter by the *moist way*.

CHAPTER XXXII.

VAPORIZATION.

Temperature of formation—Properties of vapors—Causes influencing vaporization—Evaporation in vacuo—Vaporization a cooling process—Ice machines—Effect of vapors on climate—Vapors and furnace heat—Elastic force of vapors—High-pressure engines.

690. Temperature of Formation.—Though water vaporizes most rapidly at its boiling point, the process goes on at temperatures far below this. Films of ice, for example, which have formed on a window during a cold night slowly evaporate during the day, without assuming the liquid state, if rays of the sun fall upon them. Water, in the solid state, therefore, gives off vapor—indeed, vaporization may be said to take place at all temperatures.

Faraday attempted to determine, in the case of mercury, whether there was a lower limit to the process. To this end he enclosed a portion in a vessel, and suspended a piece of gold leaf over it. He concluded that vaporization ceased when a temperature of —10° C. was reached.

Many solids—for example, iodine and camphor—vaporize rapidly without assuming the liquid state. On the other hand, no substance fails to vaporize if its temperature is raised sufficiently. Gold, platinum, and the most refractory metals under the influence of a voltaic arc of sufficient intensity may be dissipated in vapor.

In certain cases—as with camphor—light seems to influence the process. A bottle of camphor placed on a shelf, and left undisturbed for a few months, shows a copious deposit of crystals on the part turned away from the light, while not one is found on the side towards it.

691. Properties of Vapors.—Fill a matrass, which is a long-necked flask, with water to within half an inch of its mouth. On this pour ether, close the opening with the finger, and immerse it mouth down in water, B; remove the finger, and the water remains suspended in the flask. At the same time the ether rises, and takes its place in the globe of the flask, A.

Fig. 299.

Properties of vapors.

Let heat be applied to A; after a time the ether changes its form and assumes the vaporous state. The matrass may be filled with it, and yet but a small part of the fluid disappears. Pour cold water on the globe, and the ether reassumes its normal condition.

From this experiment we learn: 1st. *That vapors occupy a much greater space than the liquids which produce them.* 2d. *They are not foggy but perfectly transparent, though, as with iodine and bromine, they may be colored.* 3d. *They are easily condensed into fluid.*

A vapor, moreover, differs from a gas only in its relative condensability. *It may be defined as a gas condensing easily under increase of pressure, or reduction of temperature, while a gas requires great pressure and intense cold to produce its condensation.*

692. Causes Influencing Vaporization.—Rate of vaporization depends, 1st, on *temperature*, either as regards its degree or extent of surface exposed. A free supply yielding heat to be rapidly made latent will increase the rate. Increased extent of surface, by bringing the fluid in better contact with heat, will produce the same result. Therefore, the use of tubular boilers for locomotives and other kinds of apparatus in which steam is to be generated rapidly.

2d. *Increased surface* favors vaporization. Hence, the form given to the so-called evaporating dishes, A, Fig. 300. A given quantity of water placed in a flask and in an evaporating dish, and equal sources of heat applied, that in the latter will disappear as vapor, while the former will have lost only a small portion. When we wish long digestion with heat, the latter is the proper form of apparatus to employ. When to get rid of fluid, the evaporating dish.

3d. *Removal of the damp atmosphere* from the surface of a liquid hastens evaporation. Of this we may satisfy ourselves by blowing on a fluid in an evaporating dish, when the process will be greatly accelerated, and the temperature lowered several degrees.

4th. *Dryness of the air* also favors vaporization. It is in vain that we attempt to dry clothing when the air is saturated with moisture. In the laboratory, the hot-air oven, by raising the temperature while the dew point remains the same, offers a practical example of the application of this principle.

5th. *Pressure* exerts a notable effect on evaporation. Take the apparatus (691), place it under a tall air-pump bell, and proceed to exhaust. After a few moments, when about half the air is removed, the ether fairly flashes into vapor. Restore the pressure, and as quickly it reverts to the liquid state.

693. Evaporation in Vacuo.—Advantage is taken of the last property of vapors in a variety of manufacturing and chemical operations. When, for example, a sufficient elevation of temperature to secure a rapid vaporization would be attended by an alteration in the properties of the substances experimented upon, the process is conducted in vacuo—that is, in a space, C, connected with an air-pump by which a vacuum may be maintained through D. An application of this principle is seen in sugar boiling.

FIG. 300.

Evaporation in vacuo.

At the same time, if desired, dishes, B, containing strong sulphuric acid can be placed in a vacuum vessel, C. This favors vaporization, removing moisture from the space at a very rapid rate and at ordinary temperatures.

694. Vaporization a Cooling Process.—If ether is poured on the bulb of a Sanctorio thermometer, it vaporizes and causes a rapid contraction of the air in the instrument. Anything which favors evaporation increases production of cold and elevation of the index liquid. The cause of this is found in the fact, that for ether to assume the vaporous state it must have its caloric of vapor from the substance whereon it rests, or with which it is in contact. In this case, it takes it from the bulb of the thermometer.

Any liquid, as ether, alcohol, water, which can vaporize, if poured on the hand produces a cooling sensation. The more volatile the fluid the greater the effect. In the articles mentioned, it is in the order given. If at the same time the surface is fanned, the action is increased. If water is placed in a bulb, and surrounded with cotton soaked in ether, and the apparatus whirled in the air, the cold will be sufficiently intense to cause it to freeze. Water placed in a watch-glass which rests in another containing ether, will, if placed on an air-pump plate

and submitted to a vacuum, be quickly frozen by evaporation of the ether in the outer crystal.

Ordinary fanning cools the surface of a body. The removal of the vapor favors vaporization, and in forming it afresh the surface is cooled by the abstraction of warmth to give this its latent heat.

The cooling effect of vaporization is applied in surgery for production of local anæsthesia. A fine spray of ether is directed upon the surface by means of an atomizer. By its rapid evaporation heat is abstracted from the part and intense cold produced, attended by loss of sensibility, and the knife can be used without causing pain. A similar arrangement is utilized for freezing soft tissues in making microscope sections.

695. Ice Machines.—These depend upon the property in question. Some highly vaporizable liquid, as ether or ammonia, is caused to volatilize by diminution of pressure, accomplished by a pump. An intensely cold fluid is produced, which is used by some suitable device to abstract caloric from the water to be frozen. The portions vaporized, are by the same machine recondensed, and forced to reassume the liquid state, a large quantity of water at ordinary temperature being employed to carry off the latent heat, which becomes sensible heat when they pass from the gaseous to a liquid state. Being thus regained, they are employed to freeze more water, and thus the same quantity is made to produce an indefinite amount of ice.

In regions where ice is rare these machines are worked with considerable pecuniary profit. The loss of weight by long lines of transport, the high temperature and consequent shrinkage by melting, meeting the increased expenditure of coal required to work the apparatus.

In some hot countries water is cooled by means of *alcarrazas*, or vessels of porous earthenware. When liquid is placed in one of these a portion permeates the walls. If it is then set in a current of air the evaporation of this exterior film, by its avidity for the latent heat necessary to form a vapor, cools the contents of the alcarraza. Thus a very agreeable drink is obtained at an exceedingly moderate expense.

696. Effect of Vapors on Climate.—If the temperature is taken on the Atlantic coast of Europe, and compared with that of the same parallel on the American side, it will be found that the average annual temperature is about 10° F. higher in the former case. The cause of this is chiefly the condensation of vapor in the formation of rain. The Gulf stream made up of warm water from the West Indies, passes across the Atlantic, and bathes the whole of the northern coast of Europe with a sea

from which vapor is continually arising. This, taken up by the prevailing winds, is carried far into the interior of Europe, and coming in contact with the cold of those regions is condensed. In condensing, it surrenders its 1000° F. of caloric which gives it the vaporous form, and to this heat the moderation of climate is due. As the wind passes on, the vapor it contains is diminished. Less and less rain falls, and less latent heat is made sensible. The air is drier, and with lack of moisture its moderating effect is lost, until finally a region is reached where the greatest extremes of cold are found.

The effects of the cold, intensely dry air, on the systems of the inhabitants of these sections, and of our own western country where similar conditions exist, are well worthy of consideration. The air is not only cold, but almost entirely robbed of moisture. This passing into the lungs has a profound desiccating action, which must seriously interfere with their functions and produce inflammatory conditions.

697. Vapor and Furnace Heat.—American houses are generally heated by a furnace, which takes air into a chamber, warms it, and delivers it into the several rooms. In winter this air often has a temperature below the freezing point of water; it, therefore, contains but little moisture. In the furnace chamber it is heated to 72° F. or thereabouts. Here, therefore, there is a difference of 40° F. between the temperature and the dew-point of air, or that at which it is saturated with moisture.

Such air possesses intense desiccating power over all organic substances. Furniture is torn to pieces unless made of carefully prepared wood. Our systems are also profoundly affected unless something is done to give to the air the moisture for which it is so greedy. Generally this is accomplished by placing a large pan of water in the chamber of the furnace, which by its area may supply a portion of that required. In addition to this, vessels of water should be placed opposite the registers of rooms through which heated air is delivered. It is wonderful to note how much liquid will be evaporated in twenty-four hours. A gallon or more easily disappears.

In the treatment of inflammations of the mucous membranes of the air passages, sufficient attention is not paid to this desiccating action of furnace air. It may be modified by placing a dish of water opposite the furnace flue, and allowing towels to dip into it, which, taking it up by capillary action, present it to the incoming rush of hot air, thus furnishing a portion of the moisture it needs. At the same time, care should be taken that the pan in the furnace chamber is large, occupying the whole floor, and kept properly filled.

Proper attention to these conditions will do more to alleviate and cure a patient than all the medicine administered.

698. Elastic Force of Vapors.—Prepare a barometer by filling with mercury a tube over thirty inches in length, A, closed at one end. Carefully remove all air, and place it mouth down in a cistern of mercury, B. Let it stand in the vertical position, remove the finger and the liquid will fall from the top to about thirty inches above the cistern, and the barometer is prepared. Introduce beneath its mouth a pipette filled with ether, the tip curved for the purpose, and blow it into the interior. The mercury will instantly fall and stand at about fifteen instead of thirty inches. Incline the instrument and warm the ether it contains, the mercury will be driven lower. Cool it, and it will rise.

FIG. 301.

Elastic force of vapors.

The experiment demonstrates that ether vapor is possessed of elastic force. If we warm it, this is increased and the mercury depressed. If we cool it, it is diminished, and air pressing upon the fluid in the cistern forces it up into the tube.

By means of an ingenious device, known as the candle bomb, the elastic force of steam may be illustrated. It consists of a small bulb blown on the end of a stout glass tube $\frac{1}{8}$ inch diameter, which is drawn off as close as possible to the bulb, the end being left open. The latter is warmed, a portion of the air expelled, and the stem placed under water. By contraction of the air a little water is drawn into the bulb. The tip is then sealed. The stem is inserted in the wick of a spirit-lamp, the alcohol ignited, and the apparatus put in a safe place. After a short time a violent explosion results, the intensity furnishing a good idea of what happens when large quantities of water exert their elastic force explosively as in the bursting of boilers.

699. High-pressure Steam Engines are examples of the application of the elastic force of vapor of water. Steam is generated in a boiler, where it is confined and not allowed to escape except as used. Under these conditions its elastic force is increased, and pressures of sixty pounds, or four atmospheres upon the square inch, are easily obtained. This, admitted into a cylinder provided with a piston, gives the latter motion represented by this amount of pressure on every square inch of its surface. By suitable appliances the apparatus is made to work automatically. When the piston reaches one end of the cylinder, steam is admitted on the other side and it is driven in the opposite direction.

A reciprocating motion is thus obtained, the regularity of which is maintained by means of a fly-wheel, and constitutes the ordinary high-pressure engine.

In boilers of locomotives, marine, and other engines the solid matter contained in the water becomes concentrated as it is converted into steam, until finally, if care is not taken to blow this solution off, deposits accumulate to the thickness of an inch on the tubes of the boiler. When this has formed, as it is a poor conductor, heat does not traverse it freely. The metal which it covers becomes superheated, sometimes red hot, and oxidizes rapidly; finally, by weakening the boiler, it causes an explosion.

Various devices have been applied to prevent formation of these deposits; among them is the introduction from time to time of chloride of ammonium into the water. Another, bolting bars of zinc in the boiler. These are combined with frequent blowing off.

In low-pressure engines the difficulty is avoided by using water from the condenser, a little additional supply being provided from time to time, as from various causes it is lost. In locomotives the surest remedy in a limestone district is to collect and use rain water. Every other scheme is open to objection. Artesian wells will not answer, as they contain more dissolved mineral matter than waters which are superficial.

CHAPTER XXXIII.

LIQUEFACTION.

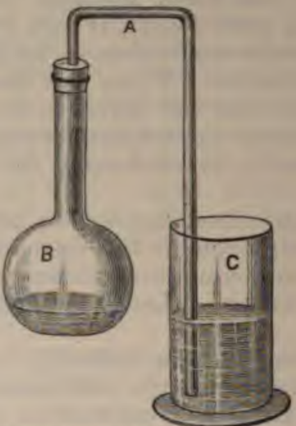
Instantaneous condensability—Low-pressure engines—Pulse glass, cryophorus, and water-hammer—Fog. Cloud. Meteorology—Rain—Rain and miasm—Snow and hail—Distillation.

700. Instantaneous Condensability of Vapors.—Adapt a tube, A, to a cork which closes the mouth of a flask, B. About three inches from the cork bend it, giving it a short and long leg. Place water in the flask, say one-sixth full, adapt the combination thereto. Apply heat and boil the liquid until steam escapes freely from the open extremity of the tube.

Having filled the apparatus full of steam, place the mouth of the long arm under water in a large vessel, C; condensation

soon begins and little by little the water rises in the tube; at last a drop falls into the flask, when instantly all the vapor it contains is condensed, a vacuum is formed, and the fluid is

FIG. 302.



Instantaneous condensation of steam.

forced up by pressure of the air on the surface of liquid in the reservoir, it rushes in with such violence that the flask is generally crushed.

701. Low-pressure Engines.—Advantage is taken of this principle in the construction of this form of engine. A large vessel, called the condenser, is kept cool and as vacuous as possible. When the piston has reached one end of the cylinder communication is established between it and the condenser. Instant condensation of the steam follows, a vacuum is formed, and pressure of the air forces the piston back; at the same time steam is admitted on the opposite side, so its movement is the resultant of two forces, pressure of steam assisted by pressure of air or a vacuum on the reverse side.

In recent marine engines the high and low pressure forms are united. A small cylinder receives the high-pressure steam at sixty or more pounds to the square inch. From this it passes into large cylinders over a hundred inches in diameter, in which it acts on the low-pressure principle. Thus the utmost effect of which steam is capable is obtained at a minimum expense.

702. The Pulse-glass, Cryophorus, and Water-hammer.—The first consists of a tube about one-half an inch in diameter with a bulb at either extremity. This contains colored alcohol. All air is carefully removed, and as perfect a vacuum as possible

obtained over the liquid. Grasping one of the bulbs in the hand and inclining the tube at a proper angle, the fluid takes up a pulsatile movement between the two, vapor being generated in one and carrying a portion of the fluid along with it to the other, where it is condensed and returned to the first.

FIG. 303.

The pulse-glass.

The cryophorus or frost-bearer is similarly constructed. In place of alcohol, the upper bulb is partly filled with water. The lower is empty; all air being removed. A freezing mixture is applied to the lower, which condensing the moisture therein, promotes evaporation in the upper. This goes on at so rapid a rate that the cold produced is sufficient to freeze the fluid in the latter. Thus we have water frozen by the application of cold at a distance. For description of the water-hammer see (196).

703. Fog. Cloud. Meteorology.—The interior of the flask in the experiment on instantaneous condensability, though filled with vapor, is perfectly clear and transparent. Not so, however, with the material which escapes from the mouth of the tube. It possesses the ordinary smoky appearance belonging to steam. Collect some of this upon a microscope slide, and examine it with that instrument. It will be found to consist of minute vesicles or hollow spheres of water. We, therefore, discover that steam while in the state of a true vapor is clear and transparent, and only assumes the form of fog when converted into these hollow spheres. What issues from the tube is not steam, it is condensed steam or water.

The formation of these vesicles, containing what is supposed to be in part ozone, is exceedingly instructive. They are quite permanent, and offer the first indication of what may be regarded as the cell wall. Indeed, it is a question whether all forms in plant life may not depend upon the water they contain. After a night's strong frost we find our windows covered with films of ice which present every variety of fern and other lowly plant forms. There is nothing present but water, and its assumption of these outlines, as it becomes converted into ice, is exceedingly suggestive of the source whence the fern forms are produced.

Cloud is by some supposed to consist of hollow vesicles, by others of solid minute particles; both are correct, as it is sometimes one, sometimes the other. The varieties are as follows:

1st. *Cirrus* is a feathery, wispy cloud, occupying the upper regions, A. Sailors call them *mares' tails*. They are at the highest elevations, and probably consist of particles of ice.

Fig. 304.

Forms of clouds.

2d. *Cumulus* is formed of rounded masses, B, convex above and flat below. They are known as cotton balls and wool packs. They prevail in summer.

3d. *Stratus* consists of horizontal sheets, C. It is low in the atmosphere. It is formed at sunset, and disappears at sunrise.

4th. *Cirro-cumulus* consists of small cumuli floating higher than cumulus. It is the variety which gives the *mackerel sky*.

5th. *Scud* from its low elevation, appears to move with great rapidity.

6th. *Nimbus* is any cloud which is discharging rain, D.

All matters relating to phenomena of the atmosphere which appear aloft are dealt with by the science of meteorology, derived from the Greek μετέωρος, signifying aloft. It was originally applied to bright objects, as shooting stars, but now includes clouds, rain, lightning, and other phenomena.

704. Rain is produced by condensation of fog vesicles in the clouds, or by coalescence of minute drops, until at last those of greater and greater size are attained and rain begins to fall.

The annual rainfall in different regions varies greatly. In equatorial parts of the globe it often reaches a depth of over 100 inches annually. In our vicinity it is from 25 to 30. Measurement is made by means of the rain gauge. For this purpose a large funnel placed in a measuring-glass may be employed. The area of the former being known, the latter gives the cubic centimetres or cubic inches of water falling thereon. The instrument should be placed on top of a post away from trees or other obstacles to its free collection from all sides of the rain which falls.

The best illustration of the variation in annual rainfall over a limited extent of country, is offered by the table of Mr. Symons, for the rainfall of Great Britain.

Lincoln and Stamford	20 inches.
Buford and Witham	21 "
London and Edinburgh	24 "
Dublin and Perth	30 "
Exeter and Clifton	33 "
Liverpool and Manchester	35 "
Glasgow and Cork	40 "
Galway	50 "
Greenock and Inverary	64 "
Dartmoor	86 "
Ben-Lomond	91 "

705. Rain and Miasm.—Whenever the annual rainfall in any section is diminished, the ponds and marshes, losing their usual supply, expose the dark muck which forms their beds to the action of the sun's rays. Under these conditions miasm of an exceedingly virulent nature is evolved. Every effort should, therefore, be made to retain the water in such places at its natural level. Under no conditions should it be drained, except in the winter season, when evolution of miasm is at its minimum.

706. Snow and Hail.—Condensation of vapor of water by the intense cold of the upper regions of the air forms minute spicules of perfectly clear ice, which may be perceived in these regions as minute floating motes. Their coalescence and union produces snow. Some idea of this intensity of cold at great altitudes is gained from the fact that Barral and Bixio, in an ascent made on July 27, 1850, at 7000 metres above the earth suddenly encountered a temperature of —39° C.

Formation of hail is usually attended by great electric disturbance. The size of hailstones is sometimes very great. Parent says, that on May 15, 1703, he saw some as large as his fist. In 1844 many fell in France which weighed five kilogrammes, or about ten pounds.

707. Distillation consists in vaporizing a liquid, such as water, and condensing its vapor. In ordinary distillation the fluid is

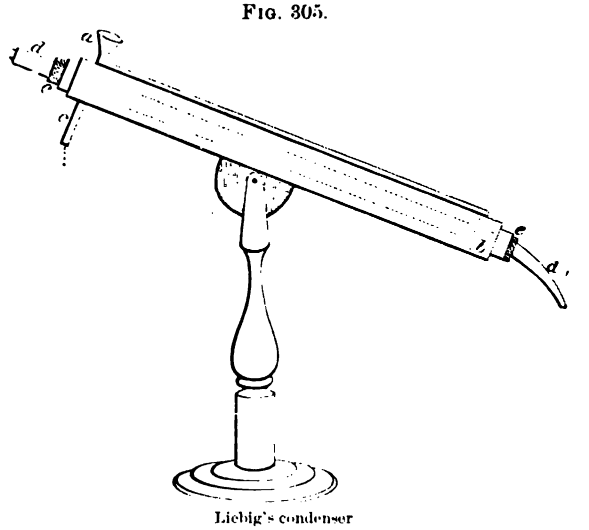
heated in a vessel called the still. It should not boil, but only simmer gently, the formation of spray, and carrying over of minute portions are thus avoided, and a purer distillate obtained. As vapor arises in the still it is received in the worm, which is a tube coiled spirally immersed in cold water. In this the steam is condensed and escapes below in a fluid state.

Special forms have been devised to secure perfect freedom from impurity. One of these is the ancient device of the *alembic*, which was contrived to return a portion of the less condensable vapors to the still.

Various modern kinds of apparatus accomplish the same result, and by exceedingly slow distillations we can obtain the most vaporizable liquids in a state of almost absolute purity.

For liquefaction of distillates in the laboratory, Liebig's condenser is used. Cold water is delivered into it by the funnel *a b*, and flowing through a metallic jacket which surrounds the tube, *e e*, keeps it cool and condenses the vapor as it passes from the

FIG. 305.



Liebig's condenser

retort through *d*. The overflow of the former is caught at *c*, and the condensed vapor is delivered at *d'*.

As a rule, the first fifth and the last two-fifths of a specimen are not collected. The first contains vapors which are objectionable. The last two, salts in increasing quantity, and the liability to formation of spray and destruction of the whole distillate is very great.

It is an excellent practice, to follow a species of fractional distillation, collecting the distillate by tenths, and mingling those which are pure.

CHAPTER XXXIV.

HYGROMETRY.

Hygrometry—Mason's hygrometer—Method of taking dew-point—Dew-point and sensation of temperature—Moisture exhaled from the lungs—Moisture exhaled from the skin—Effect of exercise on insensible perspiration.

708. Hygrometry.—We have referred to the presence of moisture in air. It is not to be supposed that this is in any way held by the air. The two things air and vapor simply coexist in a given space independently of each other. A vacuum will hold the same quantity of the latter at a given temperature as if filled with the former. The measurement of the amount of vapor in a given area constitutes the science of hygrometry.

The effect of moisture and dryness on organic substances is well known. The splitting of articles of wood, as furniture, in drying is familiar to all. The simplest hygrometers are based on this property.

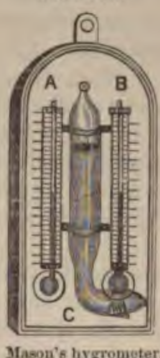
The *hair hygrometer* consists of a human hair carefully deprived of its grease by ether, one end attached to a firm support, the other to an index, arranged as a lever of the third order—that is, with the power or hair between the fulcrum and the weight and near to the former. When it expands the lever falls, and marks its effect on the scale; when it contracts, it rises. It is graduated by exposing the instrument to the full effect of: 1st, a very dry, and 2d, a saturated or wet atmosphere.

The *compensation bar hygrometer* is composed of a piece of whalebone firmly glued to a strip of wood cut across the grain. One end is attached to a fixed support, the other plays over a scale suitably divided. Fig. 289.

A *registering hygrometer* is formed of a thin rectangular strip of wood cut across the grain, about one inch wide and ten long. Pins are then passed through the four corners at equal angles of obliquity. Their points look in the same direction. When placed upon a table, if the air is damp the hinder pins take hold of the wood, and as the strip expands the fore pins are moved ahead. When it contracts the latter take hold, and the former are drawn forwards. Thus it gradually travels over the table registering the alternate expansions and contractions of the strip of wood under influence of the variations in moisture of the air.

709. Mason's Hygrometer consists of two thermometers, A and B, Fig. 306, alike in all respects. One is the dry bulb, the other the wet. The latter is covered exteriorly with a strip of linen which dips into a vessel of water, C. This by capillary attraction rises therein, and bathes the surface of its thermometer. The moisture thus raised is evaporated by the heat. If the air is dry, evaporation is rapid, and the cooling effect sufficient to depress the mercury in the thermometer a considerable number of degrees, compared with the point at which it stands in the dry bulb. If amount of moisture is greater, cooling effect and depression of the thermometer are less. The indications of the instrument are given as dry bulb so many degrees, wet bulb so many.

FIG. 306.



Mason's hygrometer.

FIG. 307.

Taking dew-point.

710. Method of Taking the Dew-point.—Of all methods of hygrometric measurement that of taking the dew-point is the most satisfactory. The apparatus required, Fig. 307, is a thin glass or silver vessel, a good thermometer, ice, and water. The operation consists first, in taking the temperature of the air, a small piece of ice is then placed in the water in the vessel, and the mixture stirred with the thermometer. The temperature is noted from time to time, and the exterior of the vessel watched for the first appearance of a coating of moisture or dew; the instant this is seen the thermometer is read, and the temperature is the dew-point, or that at which dew is deposited from the air.

711. The Dew-point and Sensation of Heat.—Variation in the dew-point affects seriously our sensation of heat. A clear day on which the thermometer stands high, but the dew-point very low, is not as unbearable as one when it stands much lower, but the dew-point very high, or close upon the temperature.

In the first case, there may be twenty degrees difference

between the dry and wet bulb of a Mason's hygrometer. All this is available for evaporation of moisture from the surface of the body, and this is, as we know, a cooling process. Considerable exercise can be taken on such a day without any unpleasant sensation of heat, for that produced in the body is removed by evaporation of water as fast as it arises. On another day, the thermometer may stand ten degrees lower, but the wet-bulb instrument showing that the air is saturated with dampness, any exertion is insufferable. There is no space for evaporation, the air, so to speak, cannot take up any more moisture, and we are drenched with perspiration if the slightest activity is attempted.

712. Moisture Exhaled from the Lungs.—In 1856 I published a series of experiments on this subject. They were made with a metallic condenser, by which the errors attending the preceding methods of experimentation were avoided, as the air passed through without obstruction. The film was one-eighth of an inch thick. The condenser was placed in a vessel of water and ice, and its temperature maintained at 32° F. At the entrance a thermometer registered the temperature of the breath, another at the exit gave that of the air escaping. The former marked 94° F., the latter 32° F. So all the moisture between these points was deposited in the apparatus. The condenser was weighed at the beginning and the end of each experiment, with the following results:

No. of respirations in one minute, 16.

Dew-point of breath 94° F.

Experiment 1.	Grains of water per minute	4.378
Experiment 2.	" " "	4.539
Experiment 3.	" " "	4.329
Experiment 4.	" " "	4.418
Average		4.416

No. of respirations per minute, 6.

Experiment 1.	Grains of water per minute	3.602
Experiment 2.	" " "	3.415
Experiment 3.	" " "	3.743
Average		3.586

No. of respirations per minute, 33.

Experiment.	Grains of water per minute	7.560

Tabulating these experiments, we obtain:

No. of respirations	6.	Grains of water per minute	3.586
" "	16.	" " "	4.416
" "	33.	" " "	7.560

From this we find that the quantity of water exhaled also depends on the rapidity of the respiratory act.

The experiments were continued for the same period, viz., twenty minutes. They were made at a temperature of 56°, and a dew-point of 49°. The same person was the subject, being a healthy adult weighing 130 pounds.

The amount of air in each respiration was calculated from the amount of water deposited, with the following result:

No. of respirations.		Cubic inches per minute.
6.	Least amount sufficing for wants of system	511
16	Average demand	622
33.	Utmost extent of respiratory operation	1077

The amount of air in each normal respiration is $38\frac{8}{10}$ cubic inches, the number of acts being sixteen per minute.

713. Moisture Exhaled from the Skin.—For examination of this problem I constructed a balance in 1862, which, with a weight of 200 pounds in each pan, easily indicated the addition of a grain to either. With this a great number of experiments were made with the following results, in which the combined loss by lungs and skin is given:

	Insensible loss per minute.	Temperature.	Dew-point.
Day rest . . .	0.79 gramme.	55°	46°
Night sleep . . .	0.47 "	50°	42°

The nocturnal loss is that which takes place during quiet, placid sleep, and the diurnal occurs when the body is kept in as perfect a state of rest as consistent with comfort, the time being spent either in writing, sitting, or reading in a recumbent posture.

To the observant, intelligent physician, who has endeavored to control the condition of his patients by seeking to give them nervous as well as mere muscular rest, the above results explain the wonderful effect which sleep has, not only in restoring the tone of the system, but also in arresting the great loss of weight and emaciation which attend so many diseases during their restless, wakeful period, but which cease almost the moment that a calm night is granted to the sufferer. For during such a night the insensible loss continually taking place is only about one-half that in simple muscular rest. A sound sleep usually marks the beginning of the stage of convalescence in any disease.

714. Effect of Exercise on Insensible Perspiration.—To determine this, a number of trials were made, which demonstrate that in health additional activity in the muscles is the chief cause of increase in the rate of loss by insensible perspiration; and that in moving the body of an adult weighing 65,000 grammes one mile, 44 grammes in addition to the usual amount are lost.

The data from which these conclusions were deduced were obtained by performing a series of experiments in which exercise, varying in duration and intensity, was undergone; and determining the increase in the rate of insensible loss.

For 10-thousandths mile per minute motion, 1.16 gramme per minute of insensible loss.
For 19-thousandths mile per minute motion, 1.67 gramme per minute of insensible loss.
For 22-thousandths mile per minute motion, 1.88 gramme per minute of insensible loss.
For 41-thousandths mile per minute motion, 2.40 grammes per minute of insensible loss.

These examples not only bear out the statement regarding the increase in loss which follows active muscular exertion, but they also show how great an influence this has in promoting insensible perspiration; a movement of forty-one thousandths of a mile per minute, which is equivalent to three miles an hour, causing the rate of loss to rise from 80 to 240, or three times the original amount. Could we have indicated to us more clearly the true channel through which the products of waste and decay in the interior of the economy during violent muscular action are thrown off?

While considering the evacuation of effete material in a form which is not appreciated by the senses, it becomes a matter of interest to determine whether the loss due to muscular action ceases as soon as exercise stops, or is continued for some time afterward. To answer this inquiry, I made a series of experiments in the months of February and July, 1863. The rate of loss before exercise was first determined. I then walked on different occasions distances varying from one to five miles, and by weighing at once, obtained the loss during exercise. I then weighed at intervals of twenty minutes, to find at what time the rate of loss became the same as before the experiment was undertaken.

The results obtained showed that the increased rate continues for some time after the exercise, and it is necessary that about an hour should elapse before the standard is regained; as illustrations, a couple of experiments are given The average per minute in the state of rest was 0.79 gramme.

Rate of loss per minute after violent exercise.

No. 1 First (20 minutes), 1.25. Second (20 minutes), 0.91. Third (20 minutes), 0.76 gramme.
No. 2. First (20 minutes), 1.65. Second (20 minutes), 1.00. Third (20 minutes), 0.90 gramme.

Both of these show a continuance of increased rate after exercise ceased. In the first, at the close of one hour, the insensible loss had not only reached, but had fallen below the normal standard, 0.79; while in the second, in which it was greater, it had not quite reached it.

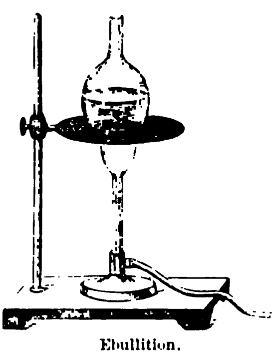
CHAPTER XXXV.

EBULLITION.

Phenomena of ebullition—Variations in boiling point—Influence of reduced pressure—Elevation and boiling point—Influence of elevation of pressure—Papin's digester—Spherical state—Effect of presence of salts—Application of heat in cooking.

715. Phenomena of Ebullition.—When heat is applied to a flask containing water, the temperature rises, and currents are established which are perfectly visible if the fluid is examined close at hand. After a while bubbles of air escape. These form and rise through the liquid without producing any serious commotion. In their turn they are followed by a singing sound, caused by steam bubbles, which gather on the bottom of the flask, and rising a short distance are condensed by the cool water above. The fluid is thus thrown into vibration and a sound emitted, well known as the singing of the kettle. This lasts for a short time, and, finally, gives place to full boiling, in which the steam bubbles maintain their form until they break on the surface.

FIG. 308.



Ebullition.

716. Variations in Boiling Point.—If water is boiled in a rough-iron pot, violent ebullition is produced at 211° F., a degree below the true boiling point. If the surface is smooth, the temperature may rise to 214° F. before it is fairly established. This is the result of adhesion between the molecules of the vessel and those of the fluid.

Many liquids, as sulphuric acid, boil in a very irregular manner, the temperature rising a number of degrees above the true boiling point. There is then a sudden violent rush of vapor, and the temperature falls to the standard, to rise again in the same manner. These irregular actions cease when some object which affords points for the escape of vapor are thrown into the vessel. In the preceding case, introduce a few pieces of platinum into the liquid and it boils in a quiet simmering

fashion, all violence is lost, and there is no further risk of breaking the vessel by the strength of the ebullition.

717. Influence of Reduced Pressure.—Of all causes which influence boiling point, that of pressure is the most profound. Take a flask of water boiling at ordinary pressure, pour it into a beaker, A, it will be cooled many degrees. Place it under the jar B on the air-pump plate C, and exhaust. In a few moments it again begins to boil, as action of the pump continues ebullition becomes more and more violent, at last it ceases. If air is then admitted, the water will be found to have a temperature so low that the hand is easily borne in it. By a diminution of pressure we have lowered the boiling point to 100° F. or less.

FIG. 309.

Reduced pressure. Reduced boiling point.

FIG. 310.

Culinary paradox.

Dependent upon this fact is a curious phenomenon known as the culinary paradox, in which water is boiled by application of cold. A flask, A, is half filled with boiling water, quickly corked, and placed bulb and neck in cold water, B. The liquid in the bulb at once begins to boil, and continues in that condition for some time. If, before it ceases, the cork is removed, there is a sudden inrush of air, showing that the interior was in a vacuous condition.

The explanation is simple; when the flask was placed in cold water, the steam filling its upper part was condensed, a vacuum was formed in which the fluid boiled by virtue of the law just demonstrated that reduction of pressure is attended by lowering of boiling point.

718. Elevation and Boiling Point.—The lowering of boiling point by elevation above the surface of the earth, led to its

utilization for measurement of height. For this purpose a thermometer with large degrees, called an *hypsometer*, is used. It is graduated to fractions. The water must be pure, it is heated to boiling, and the thermometer introduced. An elevation of about 530 feet causes a depression of 1° F. in the boiling point, and smaller elevations in similar proportions.

By the diminution in the boiling point following elevation above the surface of the earth, a position may at last be reached where the temperature of ebullition is so low that the ordinary process of cooking as applied to coagulation of albumen fails, and no effect of the application of heat will succeed in producing the desired result.

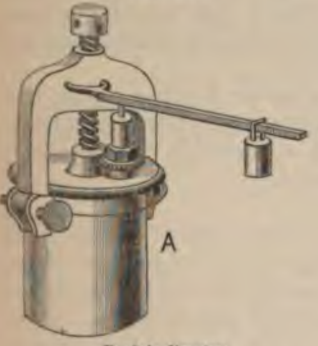
719. Influence of Elevation of Pressure.—Take a spherical boiler with three openings, the 1st for the admission of water, the 2d bearing a thermometer, and the 3d carrying a pressure gauge consisting of a tube some three feet in length which dips into mercury placed in the boiler. Pour in water until it rests on the surface of the mercury, apply heat, it soon enters into ebullition and steam escapes freely from the 1st opening through which the fluid was introduced, the thermometer marks 100° C. Close the stopcock by which the steam escaped, it begins to exert its elastic force, it presses upon the water, and this upon the mercury, and soon we see the latter making its appearance above the cap which holds the tube in place. At the same time we find the thermometer registers a higher degree. As pressure increases the temperature steadily rises until when a full atmosphere is reached, indicated by the mercury standing at thirty inches, the thermometer registers 120.6° C. The variations of boiling-point with changes in pressure are as follows:

Tension of the vapor of water.

Temperature Centigrade.	Tension in millimetres of mercury.	Temperature Centigrade.	Tension in atmospheres, 1 atmosphere = 760 mm of mercury.
—20°	0.927	100.0°	1
—10°	2.093	111.7°	1.5
0°	4.600	120 6°	2
5°	6.534	127.8°	2.5
10°	9.165	133 9°	3
15°	12.699	144.0°	4
20°	17.391	159.2°	6
30°	31.548	170 8°	8
40°	54.906	180.3°	10
50°	91.982	188.4°	12
60°	148.791	195 5°	14
70°	233.093	201.9°	16
80°	354.280	207.7°	18
90°	525.450	213.0°	20
100°	760.000	224.7°	25

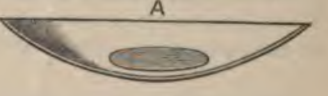
720. Papin's Digester is a closed boiler, A, in which water is heated under pressure, and its boiling-point raised. With this rise it gains increased power of solution over all kinds of animal and other substances. Tendons, cartilage, and other gelatinous bodies placed therein under a pressure of four or five atmospheres are quickly dissolved. In this manner albuminoid substances are now extracted from bones.

FIG. 311.



Papin's digester.

FIG. 312.



Spheroidal state.

721. Spheroidal State.—If a metallic vessel, A, is heated to a bright red and water thrown into it, instead of bursting into steam it quietly moves about on the surface gathering itself up into a sphere, and gradually disappears. The assumption of this form is called the spheroidal state. Though seeming to be in contact with the metal, it is not, but floats about on a cushion of steam which bears it up. Rapid evaporation from its under surface doubtless has a cooling effect, and if we could examine the temperature of the mass it is not at all improbable that it would be found quite cool.

If the metal is a thin platinum capsule and we remove it from the source of heat, the temperature declines and when it reaches a point when elasticity of the steam cushion is not sufficient to support the water, it falls on the hot surface and is almost instantly dissipated as steam.

722. Effect of the Presence of Salts.—Substances dissolved in water tend to an elevation of the boiling point, as follows:

Water pure boils at	100° C.
Water saturated with common salt boils at	109° C.
Water saturated with potassium nitrate boils at	116° C.
Water saturated with potassium carbonate boils at	135° C.
Water saturated with calcium chloride boils at	179° C.

Matters merely suspended in water do not affect its boiling point; they must be dissolved.

Water covered with a layer of oil may have its temperature raised to 120° C. without entering into ebullition, above this it boils suddenly with almost explosive violence.

The temperature of vapor escaping from boiling saturated solutions is said by Rudberg to be the same as that of pure water, but this is now doubted. One thing is certain, that by passing steam from boiling water into a saturated salt solution, the temperature of the latter is raised many degrees above that of the former. That is, steam at 100° C. may be made to cause an elevation of temperature above 120° C.

If a liquid be mingled with one of a lower boiling point, the point of ebullition is lower; when with one of higher it is raised. This, however, is not always the case, sometimes the mixture boils lower than either of its constituents.

723. Application of Heat in Cooking.—The use of moist heat in cooking may be examined according to the object in view, viz., whether to prepare a soup, or merely to cook the flesh. In the first case we desire to extract from the meat as much of its soluble constituents as possible. To accomplish this it should be exposed to the action of water at a moderate temperature.

An excellent formula for preparation of beef tea, which is the type of this group, is the following by Miss Nightingale. Cut a pound of beef into small pieces the size of dice or smaller, add a pint of cold water, and place in a saucepan on the fire. Bring to the boiling-point, and add a little salt, skim off any scum that rises. Simmer gently for one-half to three-fourths of an hour, removing any scum that appears. Strain through a hair sieve, and set aside to cool. Remove the solidified fat when cold, and serve hot, warming portions in a cup as required.

Another recipe is to place a pound of very finely minced lean meat in a bottle with a pint of water. Set the bottle in a kettle of hot water and let it simmer on the fire for an hour or so, adding a little salt. It is then passed through a sieve and treated as before.

When meat is boiled merely as an act of cooking, the following method is employed. The object is to retain the savory and nutritious juices as far as possible. It is, therefore, heated quickly on the outside by plunging it into boiling hot water, the ebullition ceases, when it recommences the pot is moved to one side to simmer. The albuminous substances on the exterior of the mass are thus coagulated, and escape of juices prevented, while

the application of moderate heat cooks the meat, without making it hard and indigestible.

In boiling eggs great care should be taken to have them as digestible as possible, where served to a convalescent. The proper way is to plunge them into a vessel of boiling hot water, but which is not boiling—that is, it should be removed from the fire. Albumen coagulates at 180° F. or thereabouts. What is desired is to coagulate without hardening. If they are boiled, the albumen becomes porcelaneous and hard. If water is treated in the manner indicated the eggs cool it at once, and the cooking is accomplished by a temperature not much above 180° F. Cooked in this manner they are simply coagulated, the albumen is in a flocculent condition; not hardened and porcelaneous, and very digestible.

CHAPTER XXXVI.

CONDUCTION AND CONVECTION.

Metals the best conductors—Different metals conduct differently—Action of gauzes on flames—The Davy lamp—Gas furnaces—Structure of flame—Blowpipe flames—Conduction by textile fabrics Liquids are poor conductors—Application in kerosene furnace—Convection of heat—Isothermal lines—Island and continental climate—Non-conduction of dew—Gases the worst conductors.

724. Metals the Best Conductors.—Take the apparatus known as the Ingenhaus's trough, consisting of a metallic box some three inches square on the end, and about eight inches long. From the front there project rods about one-eighth of an inch in diameter and three in length, made of different materials—wood, porcelain, glass, metals. Pour melted wax on these, and when cool fill the box with boiling water. The wax soon begins to melt, and the distance to which fusion extends is the measure of conducting power, providing the specific heats are about the same.

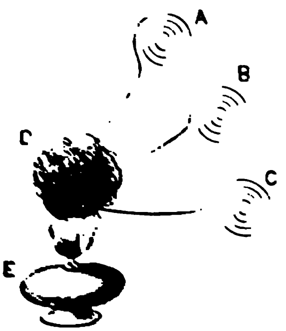
Another method is to attach shot to the bar by wax. As heat passes they drop one after another. By both arrangements it is found that metals conduct heat the best, porcelain and wood being far behind.

A simpler contrivance for exhibiting the same result consists in taking a rod of metal about one inch in diameter and six long,

and another of wood the same size. Grip a sheet of paper once around the former and hold it in the flame of a spirit lamp. It may be held therein for some time without being scorched. Then grip it around the latter. It is scorched almost at once. In the first instance the metal conducted the heat away from the paper quickly, and prevented its temperature rising; in the second the wood could not remove the heat by conduction, consequently the paper was scorched.

725. Different Metals Conduct Differently.—Take a wire of copper, A, one of brass, B, one of iron, C, of the same diameter and about twenty inches in length. On the end of each make close flat spirals of equal size. At a distance of four inches from this twine the wires together intimately, making a ball, D. Attach the apparatus to the ring of a retort stand. On each spiral place a small piece of phosphorus. Under the ball of twisted wire put the flame of a Bunsen burner, or a large spirit flame, E. The air must be as free from motion as possible. After a time the heat will have passed along the copper wire and its phosphorus will be ignited. In twice this period or longer that on the brass wire will catch fire. That on the iron will require a long period for its ignition, or may not ignite at all. Metals, therefore, conduct heat with very different rates.

FIG. 313.



[illegible]

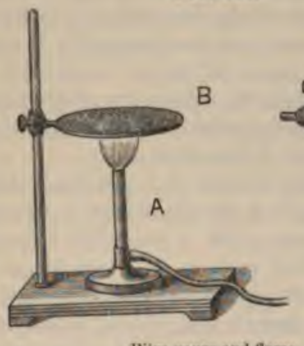
Wiedemann and Franz employed a small thermo-electric pair for measurement of the rate of conduction. Representing that of silver as [illegible], the figures for other ordinary metals are

[illegible]

726. Action of [illegible] on Flames.—[illegible] B, Fig. [illegible]

By means of this property we are enabled to study the character of flames. Looking down into one thus obstructed we find that it consists of a luminous ring, the interior being perfectly dark—that is, it does not show any combustion action.

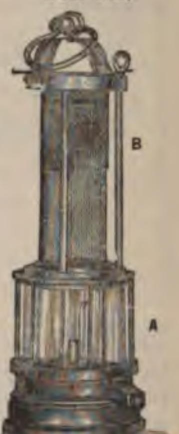
FIG. 314.



Wire gauze and flame.

727. The Davy Lamp.—This property of gauzes to prevent passage of flame is utilized in the Davy. It consists of a flame surrounded by gauze in the original and by glass, A, in Clanny's modification; above this, all direct free contact with air is cut off by a cylinder made of copper gauze, B. A lamp of this description can be lowered into a jar filled with illuminating gas without setting it on fire—indeed, the flame is extinguished. In a mixture of air and carburetted hydrogen, though there may be irregular combustion inside the lamp, the explosive atmosphere on the outside is not ignited. Therefore, it is called the safety lamp.

FIG. 315.



The Davy lamp.

Where explosions have occurred though the Davy lamp was in use, they have generally arisen by the flame being driven against the gauze by a blower or strong outward current of gas from a fissure in the walls of the mine. They have also repeatedly happened by direct exposure of the flame. In one case a workman had struck the gauze cylinder against a nail to hang up the lamp, when it was removed the exterior atmosphere gained access through the opening and an explosion resulted.

728. Gas Furnaces.—These consist of a chamber in which illuminating gas is mingled with air. The mixture is then

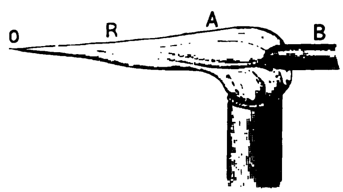
passed through a wire gauze and ignited on the opposite side. By this device a non-luminous flame is produced useful for a great number of purposes in the arts. It is also commonly employed as a source of heat in domestic economy.

729. Structure of Flame.—In connection with the action of gauzes on flame a word is to be said regarding its structure. The interior is hollow, as we have learned; it is also cold, for if we immerse a piece of paper edgewise vertically into it, we find that the luminous ring has scorched its edge, leaving two burnt places with an untouched portion between them which represents the central portion of the flame.

The same fact may be shown by pouring ether on water in a capsule some two inches in diameter. Ignite it, it gives a voluminous flame. Then with a metallic support introduce a piece of phosphorus, as it passes the luminous ring it catches fire, but the blaze is extinguished the moment it reaches the interior. Withdraw it and it is ignited, reintroduce it and it is extinguished. The experiment may be repeated many times. Hence, the centre is cold, combustion going on only in the bright ring which surrounds it.

730. Blowpipe Flames.—When by means of a blowpipe, B, air is forced into a flame, A, its whole character is changed. As it is driven on one side we notice a sharp interior blue cone, AR, just beyond or at the tip of this, R, is the hottest part. Within it—that is, toward the point of the blowpipe—there is a reduction effect from the excess of carbon present. Beyond it at O, there is oxidation from excess of hot oxygen. By proper use of its different parts and the employment of suitable fluxes, an analyst is enabled to discover the great majority of ordinary elementary bodies. Indeed, blowpipe analysis, as it is called, constitutes a special and very complete system for qualitative examination of all kinds of mineral substances.

FIG. 316.



Blowpipe flame.

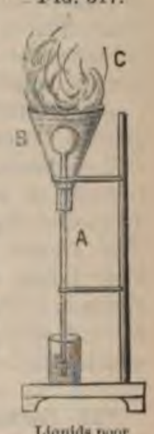
731. Conduction by Textile Fabrics.—As a rule, these fibres conduct better along their length than across it. There is also great difference according as the character of fibres varies. Rumford made a series of experiments with linen, cotton, wool, and silk to determine their relative conducting power. For this purpose he took a flask, and having provided a good ther-

mometer its bulb was adjusted to be in the middle of that of the flask. The space between the thermometer bulb and the wall was then loosely filled with the articles in succession. The time required for the temperature to rise through a given number of degrees when the flask was immersed in boiling water was noted. This became for each substance the index of its conducting power. He found that linen was the best conductor, next cotton, wool, silk, eider-down, and then the under fur of the hare.

In these experiments it was also determined that closeness and looseness of package had an important effect. The tighter, the better the conducting power. In our domestic arts we find numerous illustrations of this. Blankets, for example, are much warmer—that is, are worse conductors—the more loosely they are woven.

732. Liquids are Poor Conductors.—Take a Sanctorio's or delicate air thermometer, A. Pass its stem through that of a funnel, B, with its bulb enclosed in the body of the latter. Make the space between the tube of the thermometer and the stem of the funnel water-tight with wax. Then fill the latter with water, covering the bulb by a layer one-eighth of an inch thick. The diameter of the mouth of the funnel is supposed to be about four inches. Pour on the water some ether. Ignite it and a powerful flame, C, four inches in diameter, and twenty or more in height, is produced. Great though the heat from this is, it has no effect whatever on the index liquid of the delicate thermometer, though separated therefrom by only one-eighth of an inch of water. After a time, it is true, a slight movement may be noticed by conduction of the heat downwards by the glass. From this experiment we learn that water is a very poor conductor.

Fig. 317.



Liquids poor conductors.

733. Application in Kerosene Furnace.—The above property of non-conduction of heat is applied in kerosene furnaces. This fluid is very vaporizable, and the stoves in which it is burned would easily become heated, and probably explode, were it not for the use of water to protect the oil. The reservoir is so arranged that it can be covered by a film of water half an inch thick. Through this the tubes bearing the wicks pass. The layer of liquid is, therefore, between the flames and the top of the vessel containing the oil. It completely cuts off the passage of heat, and may be used without risk.

734. Convection of Heat.—Fill a flask three-fourths full of water, and drop into it a few pieces of amber. Apply a flame, B, to the bottom. The pieces of amber rise, pass up through the centre of the fluid to its surface, they then turn outwards to the margin, and descend along the glass to the point of application of heat. The amber merely indicates the course which the currents are taking. At the point of application of the flame the liquid is warmed, it expands, and rises through the surrounding cold fluid to the surface. Thence it again passes downwards to take the place of warmer portions. Thus a movement of rotation, or rather circulation, is established in the flask. Finally, all portions are equally warmed.

FIG. 318.

Dissemination of heat by currents.

In place of amber, ferrocyanide of copper can be employed. It is prepared by pouring a few drops of strong solution of sulphate of copper into the water in the flask, a little ferrocyanide of potassium is then added, when the dark-brown ferrocyanide of copper forms. This, after a time, settles to the bottom, and demonstrates the establishment of currents in the fluid in a most satisfactory manner when heat is applied.

An ingenious illustration of the manner in which liquids are heated, consists in taking a large test-tube, filling it three-fourths full of water, and dropping into it a piece of ice weighted with copper or lead wire. Then hold it in an inclined position, say forty-five degrees. Apply a flame to the middle of the column. The liquid above the point of application quickly boils, while that below retains its original temperature, and the ice is not melted. Thus we have ice at the bottom, and boiling water at the top of the tube. The portion above is heated by the currents established therein, but these do not pass below that point.

735. Isothermal Lines.—By revolution of the earth all parts of its surface on the same parallel should be equally heated. This, however, is not the case, owing to the interference of the great oceans, in which, by the agency of currents, there is a tendency to the establishment of equality of temperature in all its parts. If, therefore, we draw on the globe lines of equal temperature, or isothermal lines, we find that on the eastern sides of continents they pass much higher than on the western, the deflection being mainly due to oceanic currents of warm water which trend towards the northeast in the northern hemisphere, and bathing their eastern borders with warm water give a moist warm climate in regions far to the north.

Many causes influence the climate of a given region of the

earth's surface: 1st, *latitude* or distance from the equator. Other things equal, the further north we go the cooler it is.

2d, *elevation*. The higher we rise above the earth's surface the cooler it is. In the following table the results of Mr. Glaisher's averages of reduction of temperature with increase of elevation for Great Britain are given.

Height.	Clear sky.	Cloudy sky.
0 to 1,000 feet.	1° F. in 139 feet	1° F. in 222 feet
0 to 10,000 feet.	1° F. in 288 feet.	1° F. in 331 feet.
0 to 20,000 feet.	1° F. in 365 feet.	1° F. in 468 feet.

3d. *Currents in the air or winds.* According as prevailing winds set from a northern or southern direction, so is their influence for warmth or cold.

4th. *Currents in the ocean.* These we have already considered.

735 A. Island and Continent Climate.—The range of variation in temperatures is greatest in the interior of a continent, and smallest on islands in mid-ocean. This is best seen in the following tables. In both cases the temperatures are given in Centigrade degrees.

Marine climates.

	Winter.	Summer.	Difference.
Faroe Islands	3.90°	11.60°	7.70°
Isle of Unst (Shetland)	4.05°	11.92°	7.87°
Isle of Man	5.59°	15.08°	9.49°
Penzance	7.04°	15.83°	8.79°
Helston	6.19°	16.00°	9 81°

Continental climates.

	Winter.	Summer.	Difference.
St. Petersburg	—8.70°	15.96°	24.66°
Moscow	—10.22°	17.55°	27.77°
Kasan	—13.66°	17.35°	31.01°
Slatoust	—16.49°	16.08°	32.57°
Irkutsk	—17.88°	16.00°	33.88°
Jakoutsk	—38.90°	17.20°	56.10°

736. Non-conduction of Dew.—We have seen how a thin film of water prevents the passage of heat unless currents are established in the fluid. By virtue of this non-conducting power thin films of dew, made up largely of minute drops, become most important factors in protecting plants from sudden change in weather. When it has formed on their leaves and other tissues, any further loss of heat is prevented by its non-conducting power. It thus acts as a guard or protection against loss of caloric, and the plant is enabled to resist further decline in its temperature.

737. Gases the Worst Conductors.—The lack of conducting power in gases is well known. Double windows, down in birds, under fur in animals, all act by entrapping a layer of air and taking advantage of this power. Loosely woven clothing also utilizes the low conducting power of a film of air. Winters in which there is a heavy fall of snow, by the protection it affords to grain, are always followed by an abundant crop, the snow having shielded the ground from the action of frosts.

As with liquids, gases are finally warmed throughout by the establishment of currents. In illustration of this, let a piece of phosphorus be burned in a jar of oxygen, a complete circulation of gas is at once seen, the course of its molecules being indicated by the flakes of phosphoric anhydride floating therein.

CHAPTER XXXVII.

RADIATION AND TRANSMISSION.

Radiant heat passes in straight lines—Reflection of heat—Influence of surface and color—Emission of heat not superficial—Absorption of heat—Transmission of heat—Theory of exchanges of heat—Formation of dew—Application of radiant heat in cooking.

738. Radiant Heat Passes in Straight Lines.—If we stand in front of a brightly burning fire we feel the impression of heat upon the face and other parts of the body exposed to its action. If a book or other opaque object is interposed between the face and the source of heat, it is completely cut off. Remove it, and again warmth is experienced. From this we learn that heat from a fire moves in straight lines like the radii of a sphere. Hence it is called radiant, because it escapes from the body equally in all directions as radii. This effect moreover is as well marked in vacuo as in air. Heat, like light, is the resultant of vibrations in the ether.

739. Reflection of Heat.—As with light, radiant heat may be reflected when it falls on a polished surface, and the law is the same as for light. Two parabolic mirrors set in proper relation to each other, a cannon-ball, or ignited mass, placed in the focus of one, a small piece of phosphorus in that of the other. At a distance of twenty or thirty feet the phosphorus is quickly ignited. The rays of heat from the first mass are collected by

the mirror, sent forward from its surface as parallel rays, which, impinging on the face of the second mirror, are reflected to its focus, and concentrated upon the object placed there. This is known as the Florentine experiment.

Substances possess very different reflection powers.

	Reflecting power.		Reflecting power.
Silver plate	97.	Polished platinum	80.
Gold	95.	Steel	83.
Brass	93.	Zinc	81.
Speculum metal	86.	Iron	77.
Tin	85.		

Surfaces which are not polished diffuse the heat they receive in the same manner as they treat light. Each minute particle scatters it. Yet they seem to possess special powers in this respect, particularly if they are white; for example:

	Diffusive power.
White lead	82.
Powdered silver	76.
Chromate of lead	66.

740. Influence of Surface and Color on Radiation.—Take a cubical box with faces four inches square, A, and mount it on a

FIG. 319.

Leslie's canister.

vertical axis to allow it to turn thereon, and each of its faces brought in succession to the distance of ten inches from the blackened bulb of a differential thermometer. Each must be put in a different physical condition. The first polished, second slightly roughened, third very rough and somewhat dark, fourth as rough and black as possible to make it. Pour into the box boiling water, turning the first face towards the thermometer, note its effect there on reading off the number of degrees through

which the liquid moves in a given time. Repeat the experiment, in order, with each for the same period, pouring in fresh boiling water every time to avoid all question of irregularity of temperature. It will be found that the fourth or rough black surface is the best radiator, that it raises the thermometer through a given number of degrees in less time than any of the others. Next comes the third surface, then the second, then the first. The instrument is known as Leslie's canister.

Color seems, however, to be a minor factor in producing this result, for a whitened surface radiated as much heat to a thermopile as a blackened one. The bulb of a thermometer coated with a white layer of alum absorbs radiant heat better than one coated with iodine powder, which is nearly black.

741. Emission of Heat not Superficial.—For examination of this question a Leslie canister, the surfaces equally polished, is taken. One remains in its normal state, the others are varnished, an increasing number of coats being applied to each. The canister is then experimented with as before, when it is found that one, two, or more coats add to the radiation power. The improvement continues for a dozen or more, when it remains stationary for a time, and then begins to diminish. From this we find that radiant heat is given off to a certain depth from the surface of a body and is not an absolutely superficial action.

742. Absorption of Heat.—Bodies whose superficial condition enables them to radiate heat well, also absorb it well. A rough black substance is, therefore, a good absorber as well as radiator. Such bodies are bad reflectors, while good reflectors are bad radiators. An application of this is offered by an ordinary polished teapot. Its brilliant surface enables it to retain the temperature of the fluid for a long time, the higher the polish the better it acts in this respect.

Of all substances lampblack is the best absorber of heat, its index standing higher than that of any other body.

743. Transmission of Heat.—While light passes through all clear or transparent bodies with but slight loss dependent upon their color and degree of opacity, it is not so with radiant heat. A sheet of perfectly clear glass is quite transparent or *diathermous* to the heat emitted from a red-hot cannon-ball, but opaque or *athermous* to that given off by a boiling tea-kettle. Mica, rock salt, and certain other substances bear the same relation to heat, that glass bears to light; that is, they transmit it with perfect facility, whether it comes from a body with a high or low temperature, though they may not in themselves be perfectly clear to light. Indeed, a black mica almost opaque to light transmits radiant heat of low intensity with great freedom.

744. Theory of Exchanges of Heat.—A hot substance placed in a room radiates its heat to surrounding bodies and these to it also, but the former gives it off more rapidly than the latter. As a consequence, it does not receive as much as it yields. Its temperature, therefore, declines, and finally when it reaches that of the others it becomes stationary, receiving as much as it dispenses.

The cooling of a substance is due first to radiation; second, to conduction by the support on which it rests; and third, to conduction by the currents of air which bathe its surface and rise therefrom in a heated condition.

745. Formation of Dew.—In ancient times it was supposed that dew either fell from the heavens, or was evaporated from the earth; the moon, they said, exhaled cold and caused vapors to rise. We now know that it is simply a condensation of moisture from the air. At sundown, when plants no longer receive warmth from the sun, they continue to radiate off their heat into space. After a time their temperature falls to the point at which moisture from the air will condense. Dew consequently forms on their surfaces. The coating thus produced acts as a protection against a further decline. Other things being equal, deposition of moisture takes place first on surfaces dark and rough, and later on the smooth and light colored.

The presence of a cloud, by radiating heat back interferes with this process. We do not find dew deposited on a cloudy night, it must be clear, to allow heat to be freely radiated off into space, and temperature sufficiently reduced to reach the dew-point. Anything like a screen, or which can radiate heat back to the plants or other objects, acts in the same manner, and will prevent formation of dew for a long time.

For the theory of dew we are indebted to Dr. Wells, of South Carolina. It has the merit of being simple and complete and meets every condition. It is also the natural outcome of the theory of exchanges of heat.

746. Application of Radiant Heat in Cooking.—In this the same object is to be attained as in the application of a boiling heat. The albuminous material is to be coagulated, not hardened, and the juices retained. The methods are: 1st, roasting; 2d, broiling; 3d, baking; 4th, frying, which may be added as an application of dry heat.

In *roasting*, the meat is spitted (not put in an oven, that is baking), and placed in an open tin reflector in front of a bright fire. At first it is placed quite near, that coagulation of the exterior layers may be accomplished, the mass being turned on the spit until the coating is complete, it is then removed to a

little distance, from time to time basted, and the cooking concluded at a more moderate temperature.

In *broiling* the meat is treated much in the same manner as in roasting, an exterior coating of coagulated albumen is produced by a sudden strong heat, and the cooking finished at a lower degree. A little salt is generally dusted on the coals just before the meat is put on the broiler, the object being to clear the fire.

The merits of *baked* funereal meats have been sung by ancient poets, and it is well that we should leave their consideration in their hands. They are inferior in every respect to those which are roasted. The meat is apt to be imbued with the melted fat in which it rests. Such fat-soaked meat is not as digestible as that which is roasted and from which the melted fat has dropped. The action of the gastric juice upon it is interfered with, and it passes from the stomach into the intestine to be digested in the colon. The flavor, moreover, is not as pleasant as that of roasted meat.

In *frying*, meat should never be put into a cold or even cool pan. It should be hot and freshly greased. An immediate coating of the albuminoids on the exterior is thus accomplished, the article should then be turned and the opposite side coagulated in like manner. The absorption of fat is thus prevented, and if the process is conducted in a proper manner it is a very wholesome method of cooking small quantities. This, however, it is not easy to do, and it was a maxim of Napoleon that in armies the frying-pan killed more men than the bullet, by the indigestions and gastric derangements of which it was the cause.

CHAPTER XXXVIII.

ANIMAL HEAT.

Source of heat in the body—Cooling process—Hot and cold blooded animals—Effects of exposure to cold—Distribution of plants and animals—Loss of heat by the body.

747. Source of Heat in the Body.—The leading sources of heat are, oxidations of carbon and hydrogen. The results of these combinations are carbon dioxide and water. The former exists to a very small extent in the atmosphere, while the latter is present in much larger proportion. If we can prove that either is greatly increased during the process of respiration, we must arrive at the conclusion that the heat of the body arises primarily as a process of oxidation of these substances.

If two hundred cubic inches of air be drawn through lime water, a small quantity of precipitated carbonate of lime forms. If through another specimen we blow two hundred cubic inches from the lungs, a very considerable precipitate of calcium carbonate appears. We have, therefore, demonstrated that carbon dioxide is formed in the body to a very large extent, and that it is exhaled from the lungs. All processes of union of carbon and oxygen generate heat; we, therefore, find that the animal heat of our systems has its origin in oxidation of carbon.

748. Cooling Process.—By the oxidation of carbon and hydrogen contained in fats, oils, starch, and sugar, an enormous amount of heat is generated in the system. Some provision must be made for removal of the excess over and above the actual wants of the body. The means by which this is accomplished is the evaporation of water from the mucous membrane of the lungs, and skin.

Water, in its evaporation carries off no less than 1000° F. of latent heat (686). In the vapor arising from the body it is more than that. If to the 1000° of latent heat we add 212°, the sensible heat of steam, we find that the actual amount of heat in steam or vapor is 1212°. From this take the temperature of the latter as it escapes from the lungs, say 100° F., and we have 1112° as the latent heat of the vapor coming from these organs, and representing the cooling effect of vaporization on

the system. To this must be added the difference between the temperature of the air and 100° F., to obtain the full effect.

Anything which tends to increase the vapor in air lessens this action, and confines the heat generated to the system. Therefore, when air is loaded with it, and the dew-point stands high, a very profound effect is produced upon the body. Vaporization cannot take place into an air already saturated with moisture, and comfort is only found in rest as perfect as possible.

749. Hot and Cold Blooded Animals.—Between the two processes of oxidation and evaporation the balance is struck in a healthy body, and the temperature remains at a fixed degree. In all hot-blooded animals or those which possess a fixed degree any departure from this is fraught with danger. Therefore it is, that the physician watches that of his patient with such zealous care, and when he sees a tendency for it either to rise or fall abnormally, does all that lies in his power to combat these conditions.

In cold-blooded animals, on the contrary, the respiration function is less perfect. Heat is not generated to the same extent as in hot-blooded mammals and birds. Their temperature rises and falls with that of the medium in which they live, whether water or air, though it is generally a few degrees higher.

Certain animals sleep throughout the winter season. During this condition of *hibernation*, as it is called, respiration becomes exceedingly slow compared with its normal state. In the bat it falls from 200 to 30 per minute, and can hardly be detected. The tenrecs, though in a tropical climate, pass three months of the year in a torpid state. Hibernation seems to depend rather upon a scarcity of food than upon climatic conditions.

750. Effects of Exposure to Cold.—The following results were obtained, in 1872, in an attempt to determine the quantity of heat passing off from the surface of the body, by finding how much it would elevate the temperature of a known mass of cool water during a given period of time.

The manner of experimenting was as follows: Seven and a half cubic feet of cool water were drawn into a bath, and the temperature taken after careful mixing. The bath was then covered over for about four-fifths of its extent to prevent the action of currents of air, and at the close of an hour it was again tested. The rise of half a degree represented the amount of heat absorbed from the air during one hour, and was deducted as a normal error from the results afterwards obtained.

During the time occupied in determining this normal error (viz., one hour), I lay on a sofa to bring the circulatory and respiratory functions into a condition similar, as regards posi-

tion of the body, to that to which they would be submitted while in the bath. My dress during this phase of the experiment consisted of a thin flannel summer undershirt, linen drawers, and cotton socks. At the completion of the hour these were removed with as little exertion as possible and I stepped into the bath, and lay down, allowing only the head to project above the surface. At the close of an hour the temperature of the bath was again taken. I then left it, and drying myself, reassumed the same dress and lay down once more. Throughout the whole of each experiment, the dew-point, the temperature of the air, that of the bath, armpit, mouth, and temple were taken, together with the rate of respiration and the pulse.

Since in these experiments two series of phenomena are investigated, I have for the sake of clearness of description separated the results in accordance therewith, and direct attention first to the

Quantity of heat evolved from the body.

	During rest. 1st Exper. July 4.	During rest. 2d Exper. July 5.	During motion. 3d Exper. July 11.
Temp. of air	90° F.	84° F.	83° F.
Wet bulb thermometer	78° F.	76° F.	74° F.
Experiment commenced at	11.45 A.M.	12.10 P.M.	11.50 A.M.
Temp. of water when drawn	73½° F.	73½° F.	75° F.
Temp. of water at the end of an hour on entering the bath	74° F.	74° F.	75½° F.
Temp. of water at the close of an hour on leaving the bath	76½° F.	76½° F.	78° F.
Heat imparted to the water, deducting normal error	2° F.	2° F.	2° F.
Volume of water in the bath			7½ cubic feet.
Volume of the body			3 cubic feet.
Weight of the body			180 lbs.
Height of the body			5 feet 5¼ inches.

In the first and second experiments I laid perfectly still; the results therefore show the quantity of heat passing off from the surface of the body in a state of rest. This, as the table indicates, could warm seven and a half cubic feet of water two degrees in one hour. The volume of the body being three cubic feet, it follows that if we consider its specific heat as about the same as that of water (which it probably is), enough heat is evolved in the course of one hour to warm the body itself about five degrees of Fahrenheit's scale. The converse of this may also be considered as true, viz., that after death, the air being at 73°, enough is lost in the course of the first hour to cool the body five degrees. It is therefore a fact of considerable importance from a medico-legal point of view, especially in estimating the time a body has been immersed in water after recent

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drowning when the temperature of the water is about 73°, as the Croton and other streams in summer.

In the third experiment one or other of the lower extremities was alternately kept in motion during the last half of the hour. The movement consisted in extending and flexing the leg on the thigh at the rate of fifty per minute, and being performed under the surface involved considerable muscular exertion. Notwithstanding this, as the table shows, there was no material increase in the amount of heat imparted to the water. The consequences flowing from this result are of great physiological importance, but we reserve their consideration until we have completed the history of our experiments. We therefore pass to the examination of

The physiological effects of the cold bath on the body.

Experiment of July 4,—Rest—Temp. of Bath 74° F.

	1 Temp. before entering the bath.	2 Immed. after entering the bath.	3 After one hour in the bath and just before leaving it.	4 Immed after leaving the bath	5 One hour after leaving the bath.	6 Two hours after leaving the bath.
Temp. of the mouth,	99° F.	99° F.	98° F.	97° F.	97° F.	....
" " armpit,	96° F.	97° F.	95° F.	92° F.	96° F.	....
" " temple,	96° F.	....	...	....	94° F.	....
Rate of respiration, .	20	22	16	13	16	19
Rate of pulse, ...	74	73	65	54	60	72

Note.—A chill or shock was experienced on entering, and the sensation of coolness remained while in the water. Skin was dry and hot for an hour and a half after coming out. Perspiration set in and skin became cool in two hours and a half. Shortly after leaving the bath slept for thirty minutes.

Experiment of July 5,—Rest—Temp. of Bath 74° F.

	1 Temp. before entering the bath.	2 Immed. after entering the bath.	3 After one hour, in the bath and just before leaving it.	4 Immed. after leaving the bath.	5 One hour after leaving the bath.	6 Two hours after leaving the bath.
Temp. of the mouth,	99° F.	99° F.	98° F.	97° F.	97° F.	98° F.
" " armpit,	98° F.	97° F.	94° F.	94° F.	97° F.	97° F.
" " temple,	97° F.	....	95° F.	95° F.	96° F.	96° F.
Rate of respiration, .	17	21	18	15	16	16
Rate of pulse, ...	78	66	64	55	56	60

Note.—Symptoms same as in experiment 1, but not as well marked; slept thirty minutes, as in preceding.

If in the tables we compare column 1, representing the condition before entering, with column 4, representing that immediately after leaving, we find that in both the exposure for one hour to water at a temperature of about 74° F. lowered the temperature of the mouth two degrees, the armpit four, and the temple two. The rate of respiration is also diminished in one case two and in the other four movements, the pulse twenty beats in one and twenty-three in the other. It is, therefore, evident that the effects of long-continued application of a degree of cold, as that employed, is to reduce the temperature of the body and the rate of respiration slightly, while it affects the rate of pulsation in a very profound manner.

One of the consequences of this effect of cold on the action of the heart was a great reduction in the quantity of oxygen introduced into the system. The rate of pulsation being cut down nearly one-third, the quantity of oxygen conveyed into the interior of the body was diminished in a somewhat similar ratio. In a short time this began to exert its influence on the nervous centres, and there was an overwhelming disposition to fall asleep, which was unconsciously indulged in in both experiments shortly after leaving the bath, notwithstanding the strong desire to keep awake in order to record the rate of pulse and respiration at given periods.

Another evident consequence of such a sluggish movement of the blood is the disposition to congestion of various internal organs, and herein we may see a partial explanation of the action of cold in causing inflammations, especially of those organs engaged in processes of secretion and excretion.

The discussion of the results obtained has thus far been confined to the consideration of columns 1 and 4. I have followed this course because, while in the bath, a slight access of water to the armpit or to the temple causes irregularities in the thermometric indications. In the respiratory movements it is also very difficult to avoid affecting them in the act of counting. The mouth temperatures are, it is true, free from the influence of external agents, but the differences are too small to be perfectly reliable. In the pulse determinations none of these objections can be urged; they are considerable, and by counting half a minute for every record made, the error is reduced to a maximum of one beat. The movements of the heart are, in addition, free from the liability to error that exists in respiration.

Accepting the pulse determinations as being accurate and reliable indications of the effects produced, while in the bath and out of it, we return to the consideration of the tables, and compare together columns 1, 3, and 4. Recollecting that 1 represents the condition on entering, and 3 that just before leaving, after an immersion of one hour we find that the pulse

was reduced nine beats in the first experiment, and fourteen in the second. If now we compare 3, the condition just before leaving, with 4, that just after, we find that the rate of pulse has diminished eleven beats in the first and nine in the second experiment. The explanation of this extraordinary reduction is by no means clear. One thing is, however, very evident, and that is, the profound effect of the application of cold, as shown not only by the singular phenomenon of which we have just spoken, but also by the slowness with which the original rates of pulsation are regained, as demonstrated by columns 5 and 6.

The motion experiment of July 11th gave the same general physiological results as the rest trials of July 4th and 5th. The difference being, that during the former the respiratory movements became 30 per minute and the pulse 90, both regaining the rate represented in the latter very soon after cessation of exercise. Placing this great increase of the respiratory movement in juxtaposition with the failure of the exercise to cause any perceptible increase in the temperature of the bath, it is evident that the contact of cold water must put an almost absolute stop to the functions of the skin, and the whole duty of exhalation of vapor of water and consequent removal of heat is thrown on the lungs; hence the increased respiratory action, and also the special tendency of application of cold to the surface to produce inflammations of those organs by increasing the work they are obliged to perform, and raising the pulse-respiration ratio to that actually existing in pneumonia.

In conclusion, it may be observed that the primary and most important effect of the application of cold to the whole surface of the body is to reduce the action of the heart. This reduction is still further increased on removing the cold, if the application has continued for a sufficient length of time; and, as a consequence, the phenomenon of stupor or sleep appears, caused either by deficient oxidation or by imperfect removal of carbonic acid. There is also a tendency to congestion of various internal organs, especially of the lungs.

751. Distribution of Plants and Animals.—Temperature exerts an important control over the distribution of plants. The grain belt, for example, in the western part of the United States runs far to the north. As a rule, the distribution follows closely on the isothermal lines and is dependent thereon, though other conditions, as water supply, have a most important influence. On slopes of mountains in warm regions every variety of fruit is found in the range of a few miles. This is said to be the case at Quito, where tropical fruits may be cooled with ice brought from the mountain-top. Animals are also distributed

on the earth according to thermal lines. The dog and cat as companions to man are perhaps more generally found than any other creatures.

752. Loss of Heat by the Body.—In cases in which life has been destroyed, the question of the time at which the murder was committed is often one of importance. The temperature of the body at the time of its discovery is an invaluable evidence in this respect, and one by no means to be overlooked.

Many conditions are to be considered: 1st. Temperature of the air at the time; 2d. Character of the surface on which the body has lain since the crime was committed; 3d. Condition of the body as regards obesity. The last of these often exercises a wonderful effect, the temperature being retained for a very long time.

CHAPTER XXXIX.

VENTILATION AND METHODS OF WARMING.

Action of artificial lights—Action of respiration—Object of ventilation—Removal of foul air—Ventilation of sick rooms—Warming of houses—The charcoal brazier—Open fireplaces—The stove—Steam-pipes in rooms—Hot-air furnaces—Steam furnaces—Supply of vapor—Weather strips—Joule's mechanical equivalent of heat.

753. Action of Artificial Lights.—The support of combustion in candles, lamps, gas, and other artificial sources of light implies the removal of oxygen from the air of the apartment, and the substitution of carbon dioxide in its stead. The atmosphere is thus vitiated or rendered impure by a double action, the removal of the life-sustaining oxygen, and the substitution of noxious carbon dioxide.

If combustion is from any cause incomplete, carbon monoxide is also evolved, the action of which upon the economy is exceedingly deleterious.

754. Action of Respiration.—The processes of life also tend to vitiation of the air. We have seen that the animal heat of the body is the resultant of processes of oxidation or combustion. Carbon and hydrogen are actually burned therein. In their

combustion we have shown that carbon dioxide or carbonic acid gas and water are produced. This action takes place throughout the system. Every cell in the course of its life is a consumer of oxygen and a final exhaler of carbonic acid. Air, therefore, in this case also suffers a double vitiation, removal of wholesome oxygen and evolution of toxic carbonic acid gas.

Besides carbonic acid, other deleterious bodies are evolved. Ammonia in small quantity is a normal constituent of the air of expiration. Sulphuretted hydrogen also in minute quantity is given off both by skin and lungs. In addition, certain organic constituents are exhaled which are exceedingly deleterious. Their presence may be proven by breathing through colorless strong sulphuric acid, after a while it is darkened by action of the acid upon the bodies in question, their carbon being separated.

755. Object of Ventilation.—To maintain the air of an apartment in which people are living in a proper state, so that foul ingredients are removed and a copious supply of fresh invigorating air introduced, is the object of all processes of ventilation.

As a rule, it is accomplished by taking advantage of the fact that air when heated expands, and thus gains ascensional power. That from an illuminating flame has a temperature far above 2000° F., consequently though carbonic acid, which is the chief product of the combustion, is heavier than air, in the case in question it is expanded four times its original volume at the moment of formation, and, therefore, has great ascensional power. It rapidly accumulates in the upper part of the room, as we can easily satisfy ourselves by placing a chair on a table, and mounting thereon take a few inhalations of the air in that region. Little by little carbonic acid by slow diffusion passes downwards, and thus at last is equally and slowly disseminated throughout the apartment.

In products of expiration, it is true, the temperature may not be above 100° F., but the carbonic acid it contains is mingled with a very large proportion of air. In fact, it constitutes only three or four per cent. of the mixture. When cast out from the body the whole volume having a higher temperature than that of the surrounding atmosphere rises, and in like manner tends to accumulate in the upper part of the room.

756. Removal of Foul Air.—The vitiated air being in the upper part of the apartment, it is evident that there is the proper place for an opening to allow its exit. Here, then, it should be arranged, but that is not sufficient, a circulation must be established. To this end an aperture near the floor must be provided through which fresh air from the outside may enter and thus

allow exit of the foul air to continue. In this way a current is established. Close either lower or upper opening, and at once the movement ceases.

In ordinary houses flues are built to serve as the means of exit for foul air. As a rule, these are placed in the outside walls where, being in contact with the outer air, they are cold. Being cold, the current, such as it is, is downwards instead of upwards. Hold a piece of lighted paper opposite the register or opening of such a flue, and in place of the flame being drawn into it, it is driven outwards into the room. To avoid this reverse action, as it might be called, all flues intended for conveyance of foul air from an apartment should be placed in the chimney-stack where a fire is burning. By their vicinity to the smoke flue they will be heated, and containing warm air an upward movement will always take place when air is admitted at their base—that is, when they open into a room.

In this case, as in the preceding, entrance for fresh air must be provided. This is generally offered by the hot-air flue which communicates with the furnace.

757. Ventilation of Sick Rooms.—The provision of an ample supply of fresh air for a sick room is an essential condition to recovery of the patient. Yet it is not easy of accomplishment, unless at the same time we make a draught, which by suddenly chilling an exposed part of the body may produce serious consequences.

When there are no flues the windows of an apartment offer the best means. If these are of the old-fashioned kind, which slide up and down, it is a very simple matter, a small opening at the top and another at the bottom answers. The bed must be placed so that no draught falls upon it, and a curtain or screen always put in position to shield it completely from any that may be established. Where the window swings upon hinges like a door, the action is not as satisfactory, but a slight opening will generally answer. It should be strongly secured in position to prevent change during the night. By judicious use of screens the bed may be protected.

Where there are a number of windows to the room, in no case should those on opposite sides of the bed be opened, draughts would then be certainly established. One window opened in the manner stated will give all the ventilation required, and rarely do injury.

Buildings ventilated by mechanical contrivances, as fans, wheels, etc., are not uncommon. When these exist, their management is self-evident.

758. Warming of Houses.—In cold regions some means of securing artificial warmth is absolutely necessary. If with this

we can provide thorough ventilation, the best conditions for maintenance of life are secured. In various countries different means have been resorted to. Where fuel is dear it becomes an important object to husband it and produce the largest amount of heat from consumption of the smallest quantity. Where, on the contrary, it is abundant and cheap a greater degree of extravagance is allowed.

Six methods are resorted to: 1st. Charcoal braziers; 2d. Open fireplaces; 3d. Stoves; 4th. Steam-pipes in rooms; 5th. Ordinary hot-air furnaces; 6th. Steam and hot-water furnaces. Each of these we shall consider in its order.

759. The Charcoal Brazier.—Throughout the south of Europe, where fuel is scarce, the brazier is universally employed by the poor. In the open air it is not objectionable, but in a room it is about the worst form in which heat could be obtained. It consists of a mere pan or pot in which a few embers are placed and partly covered with ashes. The supply of air is insufficient, and a leading product of the combustion is carbon monoxide, which is more poisonous than carbon dioxide, since it causes a permanent change in the blood discs and destroys their power to absorb oxygen. All the gases from the fire escape into the room, and a more dangerous method of obtaining heat could hardly be devised. Indeed, when these people desire to commit suicide the favorite method is to shut themselves up with a brazier in operation, and carefully close all cracks and crevices. A few minutes inhalation of the gas suffices to destroy life.

760. Open Fireplaces.—In England the favorite method is by the open fireplace. This is an exceedingly cheery way of obtaining heat, since the appearance of a brightly burning fire is enlivening and stimulating. There are, however, many objections to its use, as well as certain advantages.

1st. It is very extravagant, as most of the heat goes up the chimney. The apartment and the articles it contains can only receive heat in the radiant form from the hot coal of the fire.

2d. There is no direct contamination of the air, since all the products of combustion pass up the chimney, which is an advantage.

3d. The air of the room is not scorched—that is, the minute floating particles are not charred and rendered irritating to the respiratory mucous membrane, as with stoves and furnaces.

4th. The ventilation is moderately good. Of course, it is limited on the side of the chimney by the height of the throat of the fireplace. From this it extends somewhat upwards, as fresh air is drawn from the windows, the lower edge of the sills being generally about the same level as the chimney throat.

5th. The draughts are bad. All air required for combustion is drawn in through the crannies and crevices about the room. If we come in contact with such fine currents of cold air, they are not only disagreeable but positively dangerous. More severe colds are caught by standing at a window for a short time exposed to these knife-like draughts than by direct exposure to severe cold outside.

Lastly, though the open fire is cheery and pleasant, in very cold weather it is impossible to warm one's self in a satisfactory manner. One is like a joint on a spit, the side towards the fire is too hot and that away from it too cold for comfort. Like the joint, one must be in continuous revolution to warm all parts equally.

761. The Stove possesses the great advantage of being the most economical of all methods. Not only is a larger portion of heat from combustion utilized from the stove itself, but by means of a long pipe a large percentage is secured as the products pass towards the chimney. Regarding other points:

1st. Direct contamination is moderate. The carbon monoxide from the fire, though it does not pass through cold iron under the severest pressures, passes through readily when it is red-hot. Tests applied to the outside of a red-hot stove easily detect the presence of carbon monoxide and dioxide. The only way to avoid their filtration through the metal is to line the stove either with fire-brick or steatite. Direct contact is thus cut off, temperature does not rise so high, and passage of noxious gases is prevented. At the same time, of course, a very considerable portion of heat is lost.

2d. As air comes in contact with the red hot surface the minute particles of floating organic matter it contains are scorched. At first this seems a matter hardly worth consideration, but when we note how numerous these are in the track of a sunbeam as it crosses a room, we are better prepared to understand how serious the objection is.

3d. If ventilation is not perfect with the open fireplace, it certainly is much worse with a stove. In the latter the opening for the entrance of air to feed the fire is close to the floor. Ventilation, therefore, is only in the lowermost parts of the room. In the upper parts, and especially near the ceiling, it is very bad.

4th. The draughts are, as with the open fire, a serious objection. Like that, the stove is fed with air entirely from the apartment. It is true, it does not consume as much, and to this extent is less dangerous.

A device called the *ventilating stove* is used in England. It is constructed in a manner to take foul air from the apartment for the maintenance of its combustion, and draw a fresh supply

from the outside, warm it, and introduce it into the room. In France they are known as Calorifères.

762. Steam-pipes in Rooms.—This method will answer very well in immense stores and shops where doors which extend from ceiling to floor are continually being opened and shut. In a living apartment, or in a hospital ward, it is very objectionable.

1st. While there may be no direct contamination, the indirect, from failure to remove the respiratory products, is serious.

2d. The air is not scorched or burned, as the floating particles are not heated above 220 or 225° F.

3d. The ventilation is absolutely *nil*. The same air is warmed or breathed over and over again, and even in hospital wards, where large openings for admission of fresh supplies are provided, patients whose beds are near these invariably stuff them with old clothing and other articles at night, to stop the draughts.

763. Hot-air Furnaces are practically stoves placed in air chambers, in which air drawn from the outside of the building is heated and delivered to the rooms of the house. The hot-air furnace being a stove, is subject to many of the disadvantages which beset that apparatus.

1st. The direct contamination from foul gas passing through the heated iron is serious. Hence, the odor often remarked as attending their use.

2d. The air is scorched as with the stove.

3d. Ventilation is excellent. Volumes of cold fresh air are drawn from the exterior of the building and forced into the rooms or wards. In place of there being an exhaustion of the interior of these, as with the open fire and stove, there is a condensation action. Air is delivered in immense quantities. Instead of there being incoming currents through the crannies and crevices, they are in the opposite direction. They all set outwards, consequently there are no draughts.

764. Steam Furnaces.—These and the hot-water arrangement avoid all the objections to the hot-air furnace. The air, instead of being heated in the chamber by a stove, is warmed by a coil of pipes through which either steam or hot water is passing.

There can of course be no contamination, either direct or indirect, since there is no communication between the interior of the pipes and the air chamber. The air is not scorched or burned, for the temperature does not rise high enough. Ventilation is as good as with the furnace, and there are no draughts. It is of all methods the best and at the same time the most expensive. Considering the great advantage of economy which the stove presents, it will doubtless for the majority of people hold its ground against all other contrivances whatever their nature.

765 Supply of Vapor.—In all the methods we have considered care should be taken to provide a free supply of water for evaporation into the air of the apartment. In the open fire, a box A, may be readily fitted over the arch of the grate just under the mantle shelf. From this a pipe, B, shaped like an inverted capital T, may pass down close to the fire, C, and receive heat sufficient to keep the water in the reservoir continually boiling. On the stove, a well-filled vessel of water should always be kept, from which free vaporization can take place. In the furnace the pans in the air chamber must be well charged, and in addition vessels of water at the registers should be used where rooms are occupied by patients or convalescents. With steam contrivances, the remedy is very simple, it is merely to allow the escape of a little steam, either continuously or as required.

FIG. 320.

Vapor generator.

765 A. Weather Strips.—In furnace-heated houses great economy is obtained by application of weather strips to the windows and outer doors. These consist of slips of metal, which embrace a narrow band of rubber. They are nailed on all sides of the window, the rubber making a tight joint against the sash. In bitter cold winter weather, when a high wind fairly blows the heated air out of our houses, these contrivances prevent this action to such an extent that rooms otherwise uninhabitable become warm and comfortable.

766. Joule's Mechanical Equivalent of Heat.—From time to time we have had occasion to speak of the conversion of work into heat, and *vice versâ*, of heat into work. The best determination we have of the reciprocal value of these two forms of energy is that given by Joule. He constructed a fan which revolved on a vertical axis in a box filled with water. The paddles on the fan moved between stationary ones attached to the sides of the box, the purpose of which was to prevent, as far as possible, the movement of the water; the axis of the fan was then caused to rotate by a thread wound around it and passed over a wheel which ran on friction rollers to a weight. The descent of this represented the energy applied, the rise in the temperature of the water the heat developed thereby. The necessary corrections being made, it was found that the heat communicated to the water by the agitation amounted to one pound-degree Fahrenheit for every 772 foot-pounds of work spent in producing it.

The mechanical equivalent for the Centigrade system is 1390. The numbers 772 or 1390, according to the scale adopted, are known as Joule's equivalents, and are represented by the letter J.

SECTION VIII.

ELECTRICITY.

CHAPTER XL.

HISTORY. THEORIES. LAWS.

First observation in friction electricity—Extended to other bodies—Conductors discovered—Du Faye's theory—Franklin's theory—Electric laws—Pyro-electricity—Electricity by pressure and cleavage.

767. First Observation in Friction Electricity.—About the sixth century before Christ, Thales, of Miletus, records the observation, that amber when rubbed attracts light bodies in its vicinity. Hence the name, electricity, from ἤλεκτρον, signifying amber. According to the philosophy of that time, this was explained upon the principle that by friction the amber became animated. Thus by a mere play upon words, men satisfied themselves that they understood the phenomena observed.

768. Extended to Other Bodies.—Under this system the observation of Thales remained without development until the sixteenth century or for over two thousand years, when Gilbert, physician to Queen Elizabeth, found that the property in question was also enjoyed by glass, resin, and a number of other substances. All of these when submitted to friction showed the same power to attract light substances.

In 1670, Boyle discovered the electric spark; closely following this, the so-called medicated tubes were invented. These consisted of a stout tube filled with jalap powder, or some other drug. It was rubbed with a silk handkerchief and the sparks drawn off from a knob in which it terminated at one end. These sparks were supposed to carry the medicinal virtues of the drug with which the tube was filled. Though, of course, they did not possess any power over that of the spark from an ordinary tube, they served the purpose of extending a knowledge of this form of electricity throughout Europe. Very soon charlatans were travelling in every direction administering sparks from medicated tubes to persons suffering from every conceivable form of disease.

769. Conductors Discovered.—In 1729 Gray discovered conductors and non-conductors. It is related that while experimenting with a medicated tube, he found that if the brass ball at its extremity was connected with it by a string, the electric virtue, as it was called, passed along that to the ball and imparted a charge to it, so that it attracted light bodies. Extending his experiment, he found that the charge could pass along a string from the upper window of his house to the area, a distance of thirty feet.

Having satisfied himself of the correctness of his observation, as was the fashion, he invited a number of friends to witness it. When the assemblage had gathered, being willing, as he relates, to perform the experiment handsomely, he provided a silken cord in place of the common hempen string formerly used. Taking his station in the window, and submitting the medicated tube to strong fricton, he found that the pieces of paper in the area remained motionless. He then substituted the hempen string, when, without difficulty, the light bodies were attracted.

Thus Gray stumbled upon the fact that while some bodies transmit the electric virtue, others fail entirely in that power. In short, he had discovered the existence of conductors or anelectrics, and non-conductors, insulators, electrics, dielectrics, or idioelectrics.

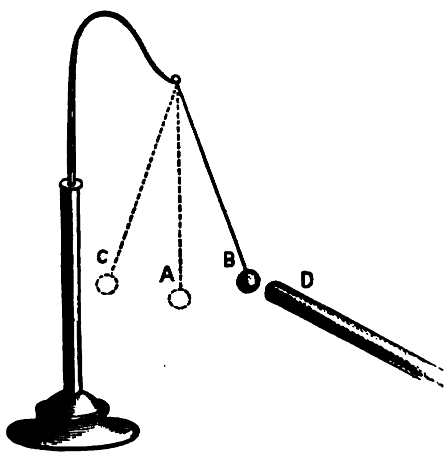
Table of Conductors.

Conductors in their order of power.	*Non-conductors, insulators, or electrics, in their inverse order.*
Metals.	Dry metallic oxides, including fused alkalies and earthy hydrates.
Charcoal.	Oils, the densest the best.
Plumbago.	Ice below 0° F.
Strong acids	Phosphorus.
Soot and lampblack.	Dry chalk and lime.
Metallic ores.	Lycopodium.
Metallic oxides.	Caoutchouc.
Dilute acids.	Camphor.
Saline solutions.	Minerals, non-metallic.
Animal fluids.	Marble.
Sea-water.	Porcelain.
Rain-water.	Baked wood and dried vegetables.
Ice and snow above 0° F.	Dry paper, parchment, leather.
Living vegetables.	Dry gases.
Living animals.	Wool, hair, feathers.
Flame.	Dyed silk.
Smoke.	Bleached silk.
Vapor.	Raw silk.
Salts.	Glass and vitrified bodies, including diamonds and transparent crystallized minerals.
Rarefied air.	Asphaltum.
Dry earths.	Wax.
Massive minerals.	Sulphur.
	Resins and gutta-percha.
	Amber.
	Shellac.

It must be understood that there is no such thing as absolute conduction and non-conduction. The terms are merely relative. In the table, that power gradually diminishes throughout. The metals, which head it, present more or less resistance to the passage of electricity. The substances which close it, allow a small amount to pass.

770. Du Faye's Theory.—Let a tuft of cotton or a ball of pith, A, be suspended by a silken cord. Then excite a glass rod, D, strongly with a silk handkerchief covered with a little mosaic

FIG. 821.



Electric pendulum.

gold (bisulphide of tin); bring the rod in the vicinity of the cotton, it is at once attracted, B. Then rub the latter in various parts with the former, without touching it with the hand; now on exciting the rod the cotton is repelled, C. Substitute for the glass rod a roll of sulphur, excite it by friction, present it to the cotton, and it is at once attracted. The apparatus is known as the electric pendulum.

From this experiment we learn that *there are two kinds of electricity, the first called vitreous or glass electricity; and second resinous or resin electricity. A body electrified by a charge from the vitreous kind is repelled by a vitreously electrified body.* In like manner, the roll of sulphur would first attract a light body, and after it is charged repel it; in other words, *bodies electrified alike repel each other.* If, however, to the vitreously electrified ball of cotton, the resinously electrified sulphur is presented, the ball is attracted. Therefore, *bodies electrified differently attract each other.*

771. Franklin's Theory.—We do not have two kinds of heat, only one, and if that in a body is deficient in quantity we say it is cold. So by Franklin's theory, there is but one kind of electricity. Of this all bodies have a normal or natural charge. If we do anything to increase this, we say it is in the positive or plus state. If we take away a portion, we say it is negative or minus. Electric conditions may, therefore, be represented by the + and — signs. Whichever theory we accept, these signs are now used for both. In Du Faye's the + sign represents vitreous, and the — sign resinous electricity.

While Franklin's is the more philosophical, there are certain phenomena not easy to explain upon that basis, but they are clear at once under the operation of Du Faye's. For example, the opposite passages of two charges from a Leyden vial when discharged through a piece of card-board.

772. Electric Laws.—1st. The general law of attraction and repulsion may be briefly stated as follows: Like electricities repel; unlike attract.

2d. The force of repulsion between two bodies electrified alike is inversely as the square of their distances.

3d. At a given distance the attractive and repulsive forces of electrified bodies are as the product of the quantities of free electricity they contain.

Bodies giving vitreous electricity if rubbed with the one that follows it, and resinous if rubbed with the one that precedes it.

1. Catskin.	8. Cotton.	15. Amber.
2. Diamond.	9. Linen.	16. Sulphur.
3. Flannel.	10. White silk.	17. Caoutchouc.
4. Ivory.	11. Dry hand.	18. Gutta-percha.
5. Rock crystal.	12. Wool.	19. Prepared paper.
6. Wood.	13. Sealing-wax.	20. Collodion.
7. Glass.	14. Colophony.	21. Gun-cotton.

773. Pyro-electricity.—Electricity of the same nature as frictional may be developed by heat in the tourmaline, cane sugar, and other bodies. The former should be suspended horizontally by a silken thread in a glass cylinder placed on a metal plate, which can be heated. The phenomena are only developed at temperatures between 10° and 150° C. As the plate is heated, the crystal becomes charged with electricity. An electrified glass rod presented to one end repels it, to the opposite attracts it. As it cools, it first loses its charge, the poles then reverse, that which was positive becoming negative, and negative positive.

The name *analogous* pole is given to that end which is positive while the temperature is rising, and *antilogous* to that which is negative.

774. Electricity by Pressure and Cleavage.—If a disk of wood covered with oiled silk, and a metal disk, each provided with insulated handles, are pressed firmly together, and then separated suddenly, the latter is found to be electrified. A crystal of Iceland spar pressed between the fingers becomes positively electrified; cork, rubber, and a number of substances exhibit the same property if insulated. Sudden separation of bodies develops the best effects.

Cleavage also produces electric disturbance; mica, paper, and all poor conductors, if suddenly separated in the dark give a flash of phosphorescent electric light. If glass handles are fitted on each side of a piece of mica, and it is suddenly torn asunder, one piece shows positive, and the other negative disturbance. A stick of sealing-wax, if broken, shows different electric conditions in its two ends.

Other sources of electricity, such as chemical action and magnetism, exist.

CHAPTER XLI.

MACHINE AND EXPERIMENTAL ILLUSTRATIONS.

Parts of electric machines—Cleaning and preparing the plate—The spark in air—The broken spark—Electric aura—Discharge in vacuo—Charging the body—Attraction and repulsion illustrated—Electric bells—Electric vane—Conduction illustrated—The electrophorus—Hydro-electric machine.

775. Parts of Electric Machines.—For the advantageous study of our subject, it is necessary that we describe the electric machine, though there are certain matters involved therein, including the action of points, which for the present we must take for granted.

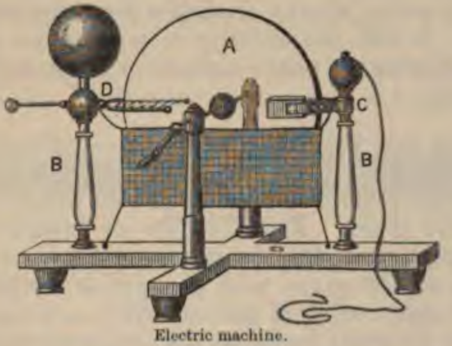
In the early days of electricity machines were constructed of cylinders of sulphur, of glass, and plates of glass. The former were mounted on an axis revolved by a winch, while the hand acted as a rubber. Electricity was collected by a row of points on the opposite side, which communicated with the prime conductor. These machines are very apt to burst under influence of friction, and their low conducting power for heat. They have gone out of use.

The next, the glass cylinder, a reproduction of the sulphur, has also passed away.

The third or plate form is the only one now in use. Of its parts we give a description. They are four in number: 1st, the plate or electric; 2d, the insulators; 3d, the rubber or excitor; 4th, the prime conductor and points.

The plate or electric A is mounted on an axis on which it revolves by agency of a winch supported by two columns fixed

FIG. 322.



Electric machine.

firmly into the base of the machine. The plate may be all the way from a few inches to six feet in diameter. It is glass or hard rubber.

Opposite its circumference, and a few inches therefrom, are the two insulators B B, which are stout glass supports fixed firmly into the base of the apparatus, and intended to carry, one the rubber, the other the prime conductor.

The rubber C varies in size with the instrument. It is supported by one of the insulators and occupies the position of a horizontal radius to the axis of revolution on one side of the plate. It consists of two pieces which should grasp the plate on opposite sides at its circumference, and extend from the margin about half way to the axis. It must be well padded, and grasp firmly. When used its parts should be coated with mosaic gold or amalgam, which greatly promote development of electricity. By means of a screw, the grip of the rubber is increased or diminished.

The prime conductor D is supported by the insulator on the opposite side of the plate. This is placed at a distance therefrom, and carries the former on its top. From the prime conductor an arm projects, extending horizontally to a point midway between the circumference of the plate and its axis. The inner surface of this presents a series of points towards the plate. These take off the charge developed by the rubber, and store it upon the prime conductor, from which it cannot escape, as it is mounted on an insulating support.

In the machine thus described the rubber and prime conductor are insulated; in this condition it would give very feeble results. If vigorous action is desired, and a development of positive electricity, the rubber ball must be put in free electric communication with the earth. Then on revolving the plate a torrent of positive sparks is obtained. If we desire negative electricity, the prime conductor is put in communication with the earth. The rubbers are insulated. On throwing the instrument into action sparks are taken from the ball attached to the rubbers. It will, therefore, give positive or negative electricity, according as the prime conductor or the rubbers are connected to earth.

776. Cleaning and Preparing the Plate.—Differences in the hygrometric character of glass produces variation in the character and power of the plate. The latter should always be made of a non-hygrometic glass. The supports or insulators must also be non-hygrometic. Before the instrument is used the insulators and plate should be wiped with a clean, dry, warm silk handkerchief, to remove all dust and moisture. The plate may be cleansed by a thorough washing, the last materials used being pure ammonia and ether.

777. The Spark in Air.—No phenomenon in nature can be confounded with the electric spark. Its light, its snap, its course,

FIG. 323.

Electric spark.

are perfectly characteristic. If the machine is put in action, and the knuckle presented to the prime conductor at a short distance therefrom, a short straight spark passes from the ball

the finger, or it may be received upon another ball, as at A. the distance is increased its character changes. It becomes -zag in its course. If still further increased, projections of ht from each angle are produced, as in the lower figure. At t the limit is reached and it ceases.

As each spark passes, it is attended by a snapping or crackling nd, which, when it takes place between eight-inch spherical ulated balls connected with a powerful induction coil, is as d as the discharge of a pistol.

'78. **The Broken Spark.**—If small disks of tinfoil are pasted on lass tube, with a small interval between them, and the latter

Fig. 324.

Broken spark.

sented to an excited prime conductor, the spark jumps from ce to piece of the foil, and is thus subdivided into a hundred more smaller ones. The added length of these is not quite ıal to the original single spark which the machine will give. In this manner, various devices can be traced on glass plates ich, on being brought into communication with the machine, suddenly lighted up and yield a very pleasing effect.

'79. **Electric Aura.**—If a point is attached to the machine and instrument thrown into action, the electricity escapes there-

Fig. 325.

Electric aura.

from in the form of a brush. If the hand is approached to the point it gives a sensation as though some one was breathing upon its surface. In a dark room the aura is seen as a diffuse light escaping from points and spreading out in a brush-like form. As the hand is approached towards the point the aura at last disappears, and is succeeded by short pungent sparks, which cause an irritating effect upon the skin. If the electricity is positive, an extensive brush is formed; if negative, a brilliant point.

The ozone or electric odor so commonly perceived in the vicinity of a machine in full action, is stronger with the aural than with the spark discharge.

780. Discharge in Vacuo.—If the electric terminals pass into the interior of a tube which is exhausted by an air-pump, the distance through which the spark can pass is greatly increased. With an ordinary machine it may easily be made to reach four or five feet. Its character also undergoes a change, the snapping sound disappears, and it takes the form of a waving or straight rod of light extending from one terminal to the other.

By changing the gas contained in the tube—that is, having the residue air, hydrogen, carbonic acid, etc.—the color of the discharge varies.

The electric egg is an oval or egg-shaped vessel of glass, which can be rarefied in the interior. Its terminals brought into connection with the machine, give a variety of forms of discharge dependent upon the degree of rarefaction and strength.

781. Charging the Body.—If a person is insulated by standing on a thick sheet of glass, or on a stool with glass legs, and the hand laid on the prime conductor, when the machine is thrown into action the body becomes charged. The hair stands out, every one repelling its neighbor. Under this condition if another person approaches his hand to the charged individual, a very strong spark passes which affects both alike, producing involuntary contraction of the muscles in the vicinity of the parts between which it passed.

782. Attraction and Repulsion Illustrated.—If two balls of pith are connected by a linen thread ten inches or a foot in length, and the latter suspended by its centre from the knob of the prime conductor, on exciting the machine the former are at once repelled. Present an excited glass rod, and it repels them. Present a piece of excited sulphur, and they are attracted. In a jar which stands upon a metallic plate, place a number of gilt pith balls. Let a knob in communication with the machine project therein to a distance of three or four inches from the plate closing its mouth. Exciting the machine the balls are

alternately attracted and repelled with violence by the knob. The experiment is known as that of electric hail.

Place a piece of gold leaf an inch square between circular plates of tin ten inches in diameter; the upper in communication with the machine, and the lower with the earth. Make the distance between the plates four or five inches. Excite the machine and at once the gold leaf rises, becomes erect, and takes on a graceful dancing movement between the two plates. The vigor of gyration depends on the degree of excitation.

783. Electric Bells.—Take a rod of metal and attach it to the machine so that it occupies a horizontal position. From the centre suspend a bell by a silken cord, and put it in communication with the ground by a chain; from each extremity suspend others by good conductors. The bells should hang some two or three inches apart. To the centre of each space between the points of suspension, attach a silken thread which carries a button at its lower extremity, the length must be adjusted to have the buttons hang opposite the rims of the bells; throw the machine into action, the electricity passes down the chains to the outer bells. These are excited and attract the buttons, which strike them, producing a ringing sound. Becoming charged they are repelled to the central bell, they strike it, discharge their electricity into the ground, and are again attracted by the outer bells. Thus a continued ringing is produced, which is an illustration of electric attraction and repulsion. The experiment is known as the electric chimes.

FIG. 326.

Electric chimes.

FIG. 327.

Electric vane.

784. Electric Vane.—Take six pieces of brass wire some six inches long, sharpen their ends to a fine point, bend them as in Fig. 327. Then attach the blunt ends to the rim of a button as radii at equal distances with the points all looking the same way. The button is then mounted upon an insulated vertical axis, so the whole arrangement can revolve freely thereon. Now connect the vane to the machine, and throw the latter into action. At once electricity escapes from the points in a brush-like form, and their recoil sets the apparatus in rotation.

785. Conduction Illustrated.—Take a secondary conductor, Fig. 328, which is of the general form of the primary conductor, and, like it, is insulated. Place it five feet from the machine; sus-

FIG. 328.

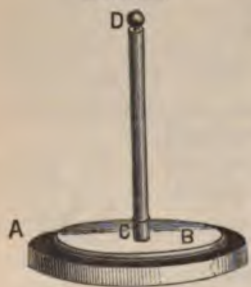
Secondary conductor.

pend a pair of cork balls at each end; stretch between the prime and secondary conductor a brass rod some six feet in length. The moment the machine is thrown into action the balls diverge from each other, showing the passage of electricity. Make a solid glass rod the means of communication between the two conductors. Throw the machine into action and there is no divergence, as glass is a non-conductor.

Gases also possess considerable conduction power, especially if hot. In illustration of this, restore the brass rod, and connect the secondary with the prime conductor. Excite the machine and the balls diverge. Hold a voluminous spirit flame under the secondary conductor, and at once they fall together. The heated air and products of combustion rising from the flame, have carried off the electric charge from the conductor.

786. The Electrophorus is an instrument by which electricity is obtained continuously and at a minimum of expense. It consists of a metallic ring ten inches in diameter, A. It should be about half an inch high. In the circular space thus formed melted shellac is poured, and allowed to rest. A disk of metal, B, of little less diameter than the shellac is provided; to its centre an insulating handle, C D, is attached.

FIG. 329.



Electrophorus.

The shellac is excited by beating it with a catskin or flannel. Then lower the plate or cover upon it, touch the margin of the former and a spark escapes; separate it from the shellac, touch its margin and another is obtained. So an indefinite number can be drawn from the movable metallic plate by alternately touching it with the finger when laid on the shellac, and separated from it.

787. The Hydro-electric Machine, invented by Sir William Armstrong, consists of an insulated boiler in which high-pressure steam is generated. This is passed through a cooling box consisting of tubes surrounded by cotton which dip into water contained therein. By partial condensation of the steam, which is an essential feature, drops of water are produced. The friction of these minute drops against the orifice from which the steam escapes develops the electricity. The steam merely fur-

nishes the propelling force. Opposite the jets is a metallic comb connected with an insulated conductor. Upon this the escaping steam impinges, and to it imparts the positive electricity with which it is charged. The jet piece is made of wood, and passage through it is hindered by a metallic tongue around which the steam is obliged to pass to reach its entrance. A pressure of several atmospheres is required, and the water used in the boiler must be distilled.

This instrument is very powerful, sparks over two feet in length being easily obtained. It works well in the open air, but in a room everything is quickly covered with condensed steam and it becomes inoperative.

CHAPTER XLII.

MEASUREMENT AND DISTRIBUTION.

Electroscopes—Electrometers—The torsion electrometer—The charge is on the surface—Distribution depends on form—Action of points—Dissipation of charge.

788. Electroscopes are instruments for the detection of electricity. The most delicate is the gold-leaf electroscope. It consists of two pieces of very thin leaf, A, about three-fourths of an inch wide and three long. These are suspended by one end so they lie face to face and touch each other. To protect them from currents of air they are placed in the interior of a jar or shade, B, through the top of which a metallic rod passes, the lower end bearing the leaves being within, the upper terminating in a ball, or plate, C, some three inches in diameter, which answers for a condenser. Within the shade, at a distance of two inches from the leaves on each side, there is a brass wire terminating above in a little ball, D, and attached below to the base of the instrument. These afford communication with the earth. The air of the jar should be kept dry by a piece of quicklime placed in an evaporating dish.

FIG. 330.

Gold-leaf electroscope.

When an electrified body is brought in the vicinity of the plate, though its distance from it is considerable, the gold leaves diverge from each other; when removed, they approach. If the divergence is strong enough to cause them to strike the

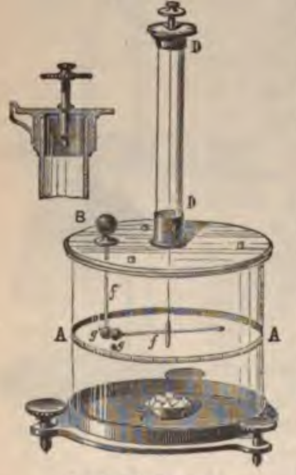
little balls, they remain divergent after the exciting cause is taken away. The character of the electricity with which they are charged may then be determined. If positive, the approach of an electrified glass rod will increase its divergence; that of sulphur will diminish it.

A simpler apparatus for detecting an electric charge is a pair of cork balls connected with a conducting thread. It is not as sensitive as the instrument previously described, but answers all ordinary purposes. For delicate physiological investigations the gold-leaf electrometer is always employed; in it lightness of the foil, its admirable conducting power, extent of surfaces, and their closeness, make it the most sensitive instrument that could be devised.

789. Electrometers are instruments for measuring the intensity of an electric charge. The quadrant electrometer consists of a rod attached to the electric machine so as to assume a vertical position. Above, it terminates in a knob to prevent loss of charge. Just below this is a graduated semicircle, to its centre a delicate wire is attached which carries a cork ball at its free extremity.

When a charge is given to the instrument the cork ball instantly diverges from the rod, the extent of this is read in degrees on the scale, being the measure of its intensity. At best this instrument is imperfect, for theoretically its action is limited to 90° of divergence. Actually the ball will rise beyond that limit. Moreover, a divergence of 60° requires many times the amount of force to produce it that is able to cause one of 30°. It is, therefore, limited to very crude determinations.

FIG. 331.



Torsion electrometer.

790. The Torsion Electrometer, or electric balance of Coulomb, consists of a cylinder of glass, A A, some five or six inches in diameter, from the upper part of this another much smaller, D D, projects. The top of the second carries a graduated scale, through the centre of which passes an axis, with an index attached traversing the scale. To the lower part of the axis a fine wire is fastened, which is carried down through the small cylinder to the centre of the large one, here it terminates in a slender rod of shellac, f, attached to it at right angles. This moves in a horizontal plane. On the wall of this cylinder a scale of

360° is affixed at A A. One end of the rod carries a gilt ball, *g*, which is mounted on an insulated support, and will retain any charge imparted to it.

Through the top of the large cylinder another slender shellac rod, B *f'*, passes vertically, which terminates in its interior in a gilt ball, *g'*, of the same size as that on the horizontally suspended rod. When this is in position the ball it carries is exactly opposite that on the latter rod just touching it, and both are insulated. The former is held in position by a knob on its upper end.

When the instrument is used the index on the small cylinder is set at 0°, and the glass cover turned until the horizontally supported ball is exactly opposite that vertically suspended. The latter is then lifted out, charged, and returned as quickly as possible. The moment it is introduced it repels the former. The amount of this repulsion is read off from the scale arranged on the large cylinder.

Let it be supposed that this is 36°. Now turn the index at the top of the small cylinder until the repulsion on the horizontal scale is reduced to 18°. Reading the amount through which the index on the small cylinder has been turned, and the consequent torsion on the wire to produce this result, we find that it is 126°, add to this the 18° of movement on the latter scale, and we have 144° as the amount required to reduce repulsion to one-half.

Again, reduce the deviation to 8.5°. For this an additional movement of the upper index through 441° is required, add to this 126 + 8.5°, and we have 575.5° as the total torsion put upon the wire to reduce the deviation to one-quarter.

Repulsions in the ratio of 1, $\frac{1}{2}$, $\frac{1}{4}$, require torsions respectively of 36°, 144°, and 575.5° to balance them. These figures show the relation of 1, 4, 16, to each other. They represent the ratio of torsions required to reduce the deviations of bodies charged with equal quantities of electricity respectively to 1, $\frac{1}{2}$, $\frac{1}{4}$.

791. The Charge is on the Surface.—Take a metallic cylinder mounted on a horizontal axis, which is glass on one side terminating in a winch, and brass on the other, ending in a ball carrying a quadrant electrometer. Let a strip of thick tinfoil be wound on the cylinder, which can be unwound by a silken thread, or wound by the winch. Wind the foil closely and charge the apparatus from the machine. The electrometer shows a certain divergence. As it is unwound, this diminishes, as it is wound, it increases. From this we see that when the superficies exposed is increased, the charge is distributed over a greater area and has less intensity. When diminished it is

disposed over a less area, and its intensity is increased, from which it is evident that the charge is distributed superficially.

792. Distribution Depends on Form.—On a *sphere* a charge is entirely on the exterior, as shown by taking a hollow insulated sphere with an opening through the top, and examining its interior with the proof plane of Coulomb's balance. No charge is found therein.

On the exterior of a *sphere* the electric density is the same for all parts of its surface.

On an *ellipsoid* it is greatest at the ends, and is at a minimum in the central regions.

On a *cylinder* it is almost entirely at the extremities.

On a *flat disk* it is hardly appreciable on the faces, and increases suddenly as the margins are reached.

793. Action of Points.—From the above, and from what has been previously stated regarding the electric brush, it is evident that the cause of the escape of electricity from points is the accumulation of the force upon them until the repellant power becomes so great that passage into the surrounding air occurs. Therefore, all points should be carefully rounded and made smooth, not only on the machine but also on all apparatus used therewith.

The presentation of a point to the machine has the same effect as though it were attached to it. In evidence of this, charge with electricity a secondary conductor, to which a pair of cork balls are attached. They immediately undergo divergence. Present to the charged conductor the point of a needle, it quickly robs it of its charge, as shown by their falling together, and this without perceptible passage of electricity from it to the point.

Connect a pointed wire to the prime conductor of the machine to make it look horizontally outwards from it. Then throw the machine into action, bring the flame of a spirit-lamp opposite the point, and it will be blown away by the electric brush escaping therefrom.

794. Dissipation of Charge.—An insulated conductor left to itself gradually loses its charge. This takes place through the supports or insulators, and the air.

The loss in the former can be diminished by decrease in their diameters. A long fibre of glass, or raw silk, makes an excellent insulator.

As respects the air, the loss takes place in two ways: 1st, *by conduction*, and, 2d, *by convection*. Highly rarefied air, and that which is moist, probably act by conduction. In dry the action is by convection. The molecules in contact with the electric

becoming charged are repelled, and new ones move in to take their place, these in their turn are also repelled. It is by this agency that escape from points is accounted for. It is a curious fact that charges of negative electricity are dissipated more rapidly than positive.

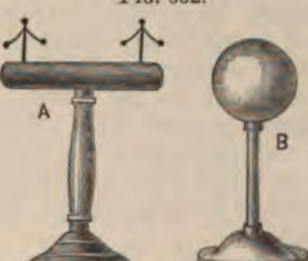
CHAPTER XLIII.

INDUCTION.

Induction described—Bound electricity—Attraction and repulsion explained—Pail experiment—Induction passes through glass—Specific inductive power—The Leyden vial—Dissected Leyden vial—Penetration of the charge. Residuum—Leyden batteries—Discharge through a card—Lichtenberg's figures—Holtz machine—Condensers—Rate of passage—Duration of spark—Mechanical effects—Physical effects—Chemical effects—Physiological effects.

795. Induction Described.—Take an insulated cylindrical conductor, A, arranged so that cork balls can be suspended from the two ends. Bring into the vicinity of one extremity a positively excited insulated sphere, B. At once there is disturbance in the cylindrical conductor. The electricity it contains under-

Fig. 332.



Induction.

goes instantaneous decomposition, the balls at either end are diverged; now take a stick of sealing wax, excite it by friction, and present it to the cork balls at the end of the cylinder most distant from the sphere, they are attracted. Present it to those at the end nearest the sphere, and they are repelled. Excite

a glass rod and examine the balls with it. It attracts those nearest the sphere, and repels those at the further end of the cylinder. We, therefore, find that the normal charge of the latter has been decomposed in such a manner, that the positive electricity is driven to the end furthest from the former, and the negative attracted to that nearest it.

Remove the excited sphere and at once the cork balls fall together. The disturbed condition of the cylinder, therefore, only lasts while the former is in its vicinity. As it is approached nearer, or removed further therefrom, the disturbance varies, being greatest when it is nearest, and steadily diminishing as it is taken to a distance.

The change described *is called electric induction or influence.* Nothing passes from the sphere to the cylinder, and the disturbance in the latter only lasts while the former is in its vicinity. It is an illustration of the law of attraction and repulsion. The sphere decomposes the normal charge of the cylinder, attracting its negative, and repelling its positive electricity. In this change the neutral condition is not quite at the centre of the latter but a little on the side towards the former. This side also shows a stronger charge.

796. Bound Electricity.—Not only are positive and negative electricities separated in the preceding experiment, but they are also in different conditions. While the positive charge is free to escape, and will pass off by any conducting channel; the negative is bound, and cannot, even though put in electric communication with the earth.

In illustration, repeat the preceding experiment, and while the cylinder is strongly under the influence of the sphere, establish connection between its further extremity and the earth. The balls at that end immediately collapse, while those at the other are more strongly diverged. By this action the neutral line has been pushed back to the earth. The whole of the cylinder is now negatively electrified. Break the earth connection and remove the sphere from the vicinity of the cylinder. The latter will now be found to be strongly charged with negative electricity, the former being positive. This method is known as *charging by induction.*

797. Attraction and Repulsion Explained.—In all electric attractions and repulsions the light body exhibits induced changes. Its normal charge is decomposed and the negative portion powerfully attracted by the positively excited body—the sphere, for example. If sufficiently light, it moves toward the excited body, and, touching it, discharges the negative portion, and is

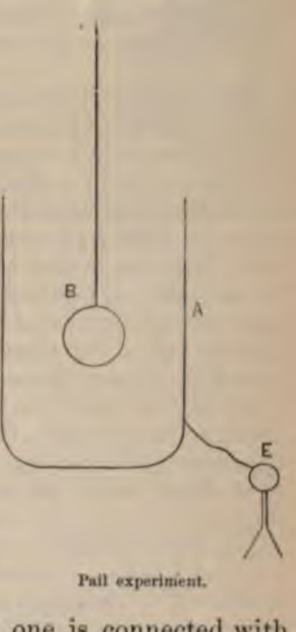
then powerfully repelled, both bodies being electrified alike or in the + state.

In place of a single cylinder conductor (795), use a number, and place them in a straight line at a slight distance from each other. Then bring the excited sphere in the vicinity of one end of the line; at once there is disturbance in the whole row. Remove it, and they relapse into their original condition.

The experiment seems to explain how conduction takes place. The molecules of the body represent the cylinders. They are at a distance from each other. When the end of the row is acted upon by an excited body one side of each molecule becomes positive and the other negative. In good conductors polarization is only instantaneous, being destroyed by the discharge from molecule to molecule. Good insulators, on the contrary, resist the tendency to discharge, and retain their polarized condition for a considerable time.

798. Pail Experiment.—Take a metallic pail, A, seven inches in diameter and eleven in height. Connect its outside by a wire with a delicate gold-leaf electroscope, E, Fig. 333. Then take a metallic ball, B, insulated by a white silk thread some four feet in length. Charge it at the machine and lower it into the pail. As it enters, the electroscope shows a divergence of its leaves. On removing it this ceases. Then lower it again, the divergence in the attached electroscope increases until a depth of about three inches is reached, beyond this it remains stationary. Let the ball touch the bottom and discharge itself, no increased divergence is seen. Remove it, and divergence continues, while the ball is found completely discharged.

FIG. 333.



Pail experiment.

From this we see that the effect produced by induction, as the ball entered the pail, was fully equal to that caused by the actual discharge of its electricity into it. Moreover, if a series of pails be placed one within the other, and insulated from each other by disks of shellac, so they do not touch in any part, and the external one is connected with an electroscope, when the ball is lowered into the inner, divergence of the leaves takes place in the electrometer, exactly as in the first instance, where only one was used.

799. Induction Passes Through Glass.—Restore the conditions of the first experiment (795), and provide in addition a sheet of glass. Bring the sphere near the end of the cylinder, the cork balls at either end of the latter show divergence. Intervene the glass between them and no change is perceptible. Remove the sphere to a distance, the balls fall together. Restore it, they are repelled, and exactly to the same distance as when the glass is removed. We, therefore, find that *electric induction or influence passes through glass* with the same facility as through air. An experiment devised by Faraday, shows that this action is due to polarization of the molecules of the medium. It consisted in taking a vessel of turpentine in which filaments of silk were diffused. Two conductors were then plunged into the fluid, one connected with the machine, and the other with the ground. The particles of silk immediately arranged themselves end to end and adhered closely, showing the conditions of the molecules. Another experiment consisted in taking a number of plates of mica closely packed, the outer provided with movable metallic coatings. The system was then electrified, the coatings removed by insulated handles, when the opposite surfaces of each were found to be electrified, the one positive, the other negative; thus showing the condition of the molecules of successive layers of the intervening electric.

800. Specific Inductive Power.—Let two hollow spheres be provided, each four inches in diameter, which like the Magdeburg hemispheres can be separated at the middle, or joined by a flange, and the interior exhausted. Through the upper half of each let an insulating conducting rod pass which communicates with a second sphere placed in the interior of the first, and separated from it by a space of about an inch wide in all its parts. Then let the inner sphere of one of the systems receive a charge, the outer being connected with the ground, the system acting like a Leyden vial. The electricity in the inner conductor is then determined by a proof plane. Suppose it gives a torsion of 250°. The knob of this instrument is then touched to that of the other. The torsion in each is found to be 125°. The two pieces of apparatus being alike, and the space between the spheres in each filled with air, the charge is equally divided between them.

Let the space in one be filled with shellac. Charge the other, put the knobs in communication, and test each by the proof plane. The charge is no longer equally divided; a portion appears to be lost, and the shellac instrument contains more than the air.

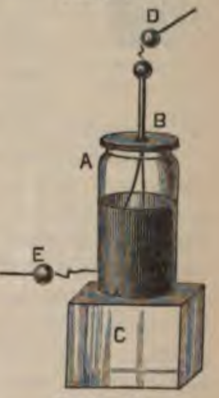
By a number of experiments Faraday arrived at the following

expressions of the specific inductive capacity of various *dielectrics*, as they are called.

Air . . .	1	Sulphur . . .	1.93
Spermaceti . .	1.45	Shellac	1.95
Resin . . .	1 76	Paraffine . . .	1.98
Pitch . . .	1.80	India rubber . .	2.80
Beeswax . .	1.86	Gutta-percha . .	4
Glass . . .	1.90	Mica	5

801. The Leyden Vial consists of a wide-mouthed bottle, A, of about a half gallon capacity. The outside and inside are both coated with tinfoil to within a couple of inches of the top, a stopper of wood, B, closes its mouth, through this a metal rod passes communicating with the inner coating below, and terminating above in a knob.

FIG. 334.



Leyden vial.

If the arrangement be put upon an insulated stand, C, and placed near the prime conductor D, of a machine in action, only three or four sparks pass to it. If a knob, E, in electric communication with the ground is then brought near the exterior coating, a spark passes to it. For every one passed from the machine to the inner coating, another passes from the outer to the knob. This continues for some time, a perfect torrent pouring from the machine to the vial. At last it ceases and the jar is fully charged. Examination shows that if positive electricity is communicated to the inner coating, it is positive electricity which escapes from the outer; but it is not the same as that which the inner coat received, for a time arrives at which the action ceases. That the electricity received by the inner coat is still there, may be proved by discharging the vial, when an exceedingly powerful spark is obtained, and a profound shock experienced, far exceeding in strength that of the sparks communicated to it.

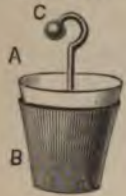
The vial can be discharged without the electricity passing through the body by means of the arrangement, Fig. 336 A, which is a pair of brass rods some eight inches in length terminating at one end in balls, and joined at the other by a hinge, so they may be adjusted to different distances. This is attached to an insulating handle.

The discharge is either instantaneous or gradual. To effect the former, touch the outer coat of the vial with one ball of the discharging rod, and then approach the other to the knob communicating with the inner coat, it is discharged with a brilliant spark and a noise like the explosion of a percussion cap. To

effect the latter, touch the outer and inner coatings alternately with a ball.

802. Dissected Leyden Vial.—The object of this apparatus is to prove that the charge is on the glass. It consists of a cone-shaped jar of glass, A, three inches in diameter at the base, five at the top, and eight high. This fits accurately into a tin jar, B, of the same diameter, but about two inches shorter. Another cone-shaped jar of tin fits the interior of the glass jar and is also about two inches shorter. When the three are placed within one another the glass projects about two inches above the tin jars. The latter act as coating to the glass. A vertical metallic rod, C, rises from the inner coating about four inches above the glass when all the parts are in position. By it electric communication is had with the interior coat.

FIG. 335.



Dissected Leyden vial.

Place the coatings in position and charge the jar at the electric machine. It acts in all respects like a Leyden vial, and will yield a brilliant flash. Charge it again, remove the inner coating by means of a glass rod, then the outer. The two may be brought into contact with each other, no spark passes. Replace them, discharge the apparatus, a brilliant spark is produced. It is, therefore, evident that the eleetricity must have been upon the glass. To prove that it is, again charge the jar, and remove the coatings. Then pass one finger on the outside of the glass below the line precisely occupied by the coating; with another finger touch the inside, instantly a shock is felt, demonstrating beyond a doubt that it is thereon.

803. Penetration of the Charge. Residuum.—Not only is the charge upon the glass, the molecules of the surface of which are polarized in opposite conditions, but it also penetrates into its substance for a certain distance. That this is the case is shown by the fact, that if a Leyden vial is charged and allowed to stand for a time, and then discharged and kept quiet a few minutes, on again applying the rod, another spark, small in comparison with the first, but exceedingly unpleasant to receive when not prepared for it, is experienced. This is the residual spark or charge. It is that portion which penetrated the glass during the first charging of the jar, and did not completely escape when it was discharged, as it required time to free itself.

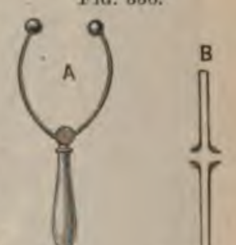
In the vial the thinner the glass the more powerful the charge. Lack of homogeneity in the latter is, however, apt to favor a discharge through that medium, and destruction of the apparatus follows.

804. Leyden Batteries.—In these a number of Leyden vials are arranged by connecting their outer coverings together by placing them on a board covered with tinfoil. The inner coatings are connected by rods. It gives a spark when discharged, which is in proportion to the size and number of jars entering into its formation.

A battery of this description is charged either directly by the machine or *charged by cascade*, as it is called. The latter is accomplished by placing the jars on insulating supports, with the outer coat of one in juxtaposition to the knob of the inner coat of the next, the last of the series connecting with earth. A spark is then given to the inner coat of the first, one of the same nature leaves its outer coat to enter the inner of the next, and so on throughout the whole line. By this method the charge required for one is made to charge the whole series. They are then placed in position—that is, their outer coats are connected in one series and their inner in another, when they are discharged in the ordinary manner.

805. Discharge through a Card.—Charge a Leyden jar, and then intervene a card or piece of pasteboard between the ball of the discharging rod, A, and the outer coating. Approach the other ball to that of the jar, and discharge it. The charge forces itself through the card, and disrupts its tissue in a curious way. The aperture is not made by a force passing in one direction, as a needle driven through a substance on one side, and drawn out with its thread on the other. This would produce an indraft at the entrance, and a fraying out of the exit. This is not what we find. On the contrary, it is as though two needles had been forced through in opposite directions, B, and their threads drawn out at the same time as a shoemaker stitches. This frays out on both sides, and is exactly what the electric spark does.

Fig. 336.



Discharging rod. Perforated card.

This fraying out in both directions by the passage of the electric spark, is held as important evidence in support of the theory of two fluids or forces. It is easily explained on this hypothesis, the two passing in opposite directions at the same time to intermingle with each other.

806. Lichtenberg's Figures.—Take a plate of shellac, the electrophorus will answer. Charge a Leyden vial, and holding it by the outer coating, trace a simple design with the knob upon the shellac. Place the former on an insulator, and take hold

by the knob and trace another design on the latter with the outer coating. A mixture of finely powdered red lead and flowers of sulphur is then shaken together to electrify it, and dusted on the surface. The powders immediately separate, the latter adheres to the pattern traced with the positive electricity, the former to the negative. Not only are they separated, but the figures are entirely different in nature. The sulphur particles

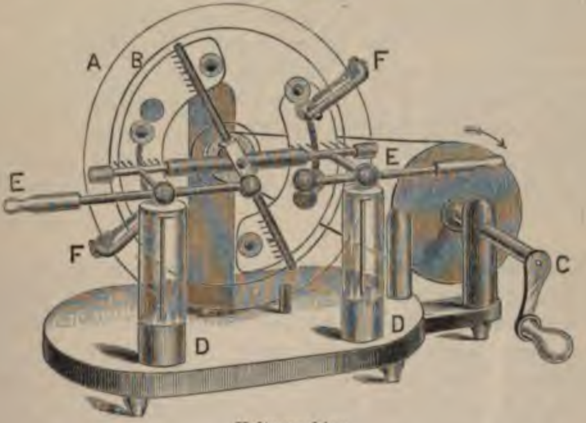
FIG. 337.

Lichtenberg's figures.

arrange themselves in branching lines, while the red lead tends to the formation of small circular spots. From this it would seem that positive electricity which has attracted the former travels along the surface more readily than the negative. The same effect is seen with electric brushes. These facts also support the theory of duality in electricity.

807. Holtz Machine.—Another phenomenon of induction is the Holtz machine, as modified by Toepler. It consists of two glass plates, one fixed, A, and the other, B, capable of rapid rotation by a multiplying wheel and band, C. Condensers, D D,

FIG. 338.



Holtz machine.

and discharging rods, E E, also form parts of the apparatus. The metallic brushes, F F, should touch the small brass knobs, but not the plate.

The machine being ready, see that the plate revolves freely without striking anywhere, then place the discharging balls close together, and turn the wheel until sparks pass between them. Then separate them gradually with a piece of hard rubber. Turning the wheel rapidly, a torrent of sparks passes between the knobs.

The action is this: "The small brass disks on the anterior surface of the plate when this is revolved rub against the metallic brushes, a small amount of electricity is thus developed and carried around to the armatures upon the back of the large stationary plate. The initial charge is thus given to this, which in its turn reacts upon the revolving plate. By this novel arrangement the old-style plate with windows is dispensed with, and the machine easily charged," the action throughout being by induction.

By means of this machine the application of this form of electricity for medicinal purposes is made a practical success.

808. Condensers.—A Leyden vial is, properly speaking, a condenser, but the term is usually applied to flat sheets of glass, or some other electric, the two surfaces of which carry metallic

coatings which are movable or not, and somewhat less in size than the sheet of glass. One of these, called the collecting plate, is connected with the machine; the other with the earth, and the glass is between them. When the machine has reached the limit of action, the face of the plate connected with the earth is covered with negative electricity drawn therefrom, and held by the attraction of the positive electricity of that attached to the machine. On the other hand, the latter not only presents the charge which the machine could normally give it, but in addition that which is induced by the negative electricity of the plate in connection with the ground.

By condensation we understand that there is *an enormous increase of electrical density on a given surface without increase of potential.*

809. Rate of Passage.—It is related that one of the kings of France, being desirous of determining the rate of passage of an electric current, ordered that 180 of his guards should form a line, each man with his hand upon the head of his neighbor. The outermost men were one to touch the outside coating of a Leyden vial, the other the knob communicating with the interior. It was thought that by this experiment it could be determined whether electricity travelled from the outer to the inner coat, or in the reverse direction, whichever way it went the man at the end of the line from which it started would first be prostrated. A trial being made, it was found that all the men were felled at the same moment. It was, therefore, concluded that the movement of electricity is instantaneous.

Though not instantaneous, the rate of passage of an electric spark is very rapid, and depends upon a number of conditions. Among these is the length of the circuit. Through a distance of half a mile, Wheatstone found, by the use of his revolving mirror, and a break of the current in three places, two close to the coatings, and the third at a quarter of a mile distant from each, that there was a retardation of the latter less than one-millionth of a second This, by calculation, gave a velocity of 288,000 miles in a second, the velocity of light being only 180,000 miles in the same time. In longer circuits the rate is much slower, through 3000 miles of an Atlantic cable it required one second for the current from a Daniell battery at one end to give deflection in a Thomson mirror galvanometer at the other.

The nature of the conductor, the insulation, and a number of other conditions, all have their effect. Other things being equal, the velocity of dynamic electricity is less than static.

810. Duration of Spark.—The electric spark lasts for a very short interval of time. Its brevity may be illustrated by means

of the revolving card. On this the colors of the spectrum are painted radiating from centre to circumference. It is driven by clock-work, and may receive so rapid a rate of motion that the colors all blend together upon the retina, and a uniform gray tint is produced. If while in rapid rotation a Leyden spark is discharged in front of it, every color stands out as sharply as though it was perfectly still. That is, the spark has come and gone before it has had time to move.

In determinations made by Lucas and Cazin, by means of lines traced on a revolving disk, it was found that the electric spark lasts from 23 to 46 ten-millionths of a second. Its duration is prolonged by an increase in the number of Leyden jars in the battery employed, and with the striking distance between the balls of the discharger.

811. Mechanical Effect.—By a powerful Leyden discharge, glass is perforated, wood and stone fractured, gases and liquids decomposed.

If a sheet of glass is supported upon a cylinder of glass, and a pointed piece of brass touches it above, and another below, on making these the terminals of discharge from a Leyden battery, the sheet is perforated.

Let two brass knobs be the terminals for an electric discharge in the interior of a glass tube an inch in diameter, and six inches long. The wires connected with the knobs must pass air-tight through the glass. Let a tube an eighth of an inch in diameter communicate with the lower part of the large tube, and be bent twice at right angles to it, so that its continuation is parallel to it. Water is then placed in the apparatus to such a height that the lower knob in the large tube projects above it. When sparks are passed between the knobs, the fluid in the small tubes is driven up, and the level immediately reëstablished, showing that the movement is not due to heat but to impact of the spark.

812. Physical Effects.—Ether, bisulphide of carbon, and a number of other liquids subjected to the passage of an electric spark are inflamed. Passed along a very fine wire the metal may be deflagrated, or driven off in vapor. Discharged upon gunpowder it is projected in all directions, but if delivered from a wet string the powder is ignited. The result in the latter case is owing to diminution in the velocity of the passage of the electricity. This principle has been applied to ignition of gunpowder for mining and engineering purposes; the apparatus is known as the electric fuse. Passed through sugar, eggs, various fruits, fluorspar, and heavy-spar, they become luminous in the dark. If sent through a wire wound around a glass tube

in which knitting needles are placed, the latter are magnetized; it will reverse the compass needle.

If a person wearing dry shoes imitates the act of skating on the carpet of a house warmed by a hot-air furnace, and then presents his knuckle to the escaping gas from a burner, it will be ignited. The use of a strong electric spark for instantaneous ignition of a great number of gas jets is well known.

The luminous effect of the spark is owing to ignition of particles of matter in its course, or of an actual transportation of matter from one terminal to the other. If different metals are used as terminals, there will be a passage of metal of one knob to the other, which will in time show a well-marked covering.

813. Chemical Effects.—Gases, such as oxygen and hydrogen, which act on each other, if mingled in proper proportion and submitted to the electric spark immediately combine. If either is in excess, it may require a number of sparks to secure complete union of the one deficient. Passed through moist air, its nitrogen and oxygen are forced to unite, especially in the presence of a solution of potassa, nitric acid being produced.

Many compound gases, as ammonia, sulphuretted hydrogen, etc., are decomposed. Carbon dioxide is separated into oxygen and carbon monoxide. Iodide of potassium is decomposed and its iodine freed, so that it will strike a blue color with solution of starch. Ordinary oxygen is converted into ozone, and a host of other examples might be cited.

814 Physiological Effects on living beings, or on those recently deprived of life. In the first case, there is violent excitement the result of action on the parts themselves, or on the nervous centres. In the second, muscular contractions imitating a restoration to life.

With large Leyden batteries small animals can be killed. Rats are killed with batteries of seven square feet of surface, and cats with one of five square yards of coated surface.

Among the results of the action of powerful discharges are "burns, superficial and deep, ecchymoses, stripping of the skin off the whole body, deafness, amaurosis, paralysis, lesions of the vascular system, transudations of liquids, and rapid putrefaction. Sometimes the bones are broken, the limbs torn and separated. In one instance the head of a man struck by lightning was crushed as by a powerful blow. On the other hand, strokes of less intensity have cured old diseases. Among other singular effects are the more or less complete stripping off the clothing."

CHAPTER XLIV.

ATMOSPHERIC ELECTRICITY.

Lightning identical with machine electricity—Electric state of atmosphere—Variation in amount and character—Origin of atmospheric electricity—Lightning—Thunder—Return shock—Lightning-rod—Aurora borealis.

815. Lightning Identical with Machine Electricity.—For this discovery we are indebted to Franklin, who had made proposals to parties in France for the demonstration in question. While waiting for the erection of a steeple in Philadelphia, by which he proposed to prove the truth of his hypothesis, and fearing lest he might be anticipated, he determined to resort to the use of a kite whenever a promising thunderstorm appeared.

For this purpose he armed the sticks of a kite with needles, and established electric communication between these and the hempen string by which it was raised. On a day when clouds indicated the approach of a storm he sallied out with his little son, to give color, as he says, to the expedition, and taking with him the kite, the front door key of his house, and a pair of cork balls connected by thread, they went to some adjacent fields. Here the kite was raised, and the string passed through the handle of the key, which served as a prime conductor. It was insulated by means of a silken cord. A promising cloud approached and he presented his knuckle to the key but failed to get a spark. After a few failures, and just as he was about to give up the experiment, a few drops of rain fell, and he remarked that the fibres of the string were repelling each other and standing out from it. Presenting his knuckle to the key he received a pretty sharp spark. Suspending the cork balls to the lower part of the key, they strongly repelled each other. Thus by exceedingly simple contrivances, Franklin demonstrated the identity of the spark of the machine with the lightning flash, and showed that the apparent difference between them was only one of intensity and not of quality.

816. Electric State of Atmosphere.—Electricity exists in the air not only in clouds, but a difference may always be found between a given station and a point above it. Various methods have been resorted to for the demonstration of such electric disturbances. Among these we may mention the projection of a ball into the air, the discharge of arrows, kites, captive balloons,

the projection of an iron rod, which is, however, a dangerous plan and cost one experimenter his life. Finally, the apparatus of Sir W. Thomson, which consisted of a small tank of water placed on the sill of a window, from this an insulated tube projected into the air on the outside, and from it the water was allowed to drip slowly. These appliances served for the collection of atmospheric electricity, the means for examination were electroscopes, either straw, pith balls, or gold leaf.

A gold-leaf electrometer with a rod four or five feet in length vertically projecting from it, will, in the open air, easily detect the difference in electric condition between the stratum in which it is placed and that reached by the point of the rod. Peltier used a gold-leaf electroscope on the top of which was a copper globe. Such an instrument raised a foot or two shows the variation in electric condition between the two strata.

817. Variation in Amount and Character.—By means of the contrivances mentioned in the last paragraph, the presence of free electricity in the atmosphere is invariable detected. When the air is perfectly clear it is always positive, varying in amount with the height of the locality and the time of day. It is not found in houses, streets, or under trees, but in the vicinity of bridges and docks, and other open spaces. On flat land it is usually perceptible about five feet above the ground.

At sunrise the charge is feeble, it increases up to 11 o'clock, it then decreases until just before sunset, and reaches a second maximum a few hours after the sun passes below the horizon. These variations follow closely upon those of the barometer, and the finer the weather the better they are marked.

With a clouded sky the electricity is sometimes positive, sometimes negative. It often changes in this respect several times in the course of the day.

818. Origin of Atmospheric Electricity.—Though our knowledge is not positive, it is generally conceded that it originates in the evaporation of water. An essential condition seems to be, that the water must contain a saline body in solution; that distilled does not show any disturbance in its evaporation.

Becquerel considers that the earth is an immense reservoir of electricity. He has shown that when earth and water come in contact, it is produced, the former taking either positive or negative, and the latter the opposite. He made his examinations with platinum plates immersed in different moist localities, or in earth and in water, and connected with a multiplier. Evaporation from either source would carry the electricity of the region into the air, and thus account for its presence therein.

Clouds are all electrified, some positively, some negatively.

The positive condition is usually found in those formed from vapors set free from the ground and condensed in the upper regions of the air. Negative are thought to result from fogs which have obtained their charge from the earth.

It is not at all improbable that the source of electricity of the air is the friction of solid and liquid particles against each other or against the earth as they are driven by wind. The strong electric excitement present when dry snow is driven by wind, strongly supports this theory of its origin.

819. Lightning is the discharge of a charged cloud. In lower regions it is white, but in upper rarefied strata it is violet. The flashes are often between points several leagues apart, and generally in a zigzag course. This is attributed to the resistance of air to its passage.

Lightning is of different kinds. 1st. The *zigzag* or linear, which moves with exceeding velocity. 2d. *Sheet*, filling the entire horizon and without distinct shape; this is the more common form, and seems to envelop the cloud as though it were a brush-like discharge. 3d. *Heat lightning* is without the appearance of clouds and without sound. This absence of noise is probably due to its great distance. 4th. *Globe lightning*, wherein the discharge takes the form of a globe of fire. The movement is comparatively slow, being often in view for ten seconds as it descends. It sometimes rebounds on reaching the ground, and often explodes with a deafening noise; this form is rare.

The course of the discharge is usually from the cloud to the earth. The latter by induction becomes charged with the opposite electricity, when their tension exceeds the resistance of air the two combine, the spark passing. Ascending lightning is occasionally observed. In this case the clouds are probably electrified negatively, the earth then having a positive charge, it passes upwards, since the latter passes through air more readily than a negative charge.

During a thunderstorm vicinity to trees, elevated buildings, and metallic masses should be avoided. Lightning discharge striking a sandy soil melts the silica and produces *fulgurites* or glassy tubes, often thirty to forty feet in length.

820. Thunder is the report which follows a lightning discharge.

The two are produced simultaneously, the time required by sound to travel through air makes the thunder seem to follow the lightning. The rate of movement is about 1100 feet per second, therefore, the distance of the flash can be easily calculated by observing the time between it and the peal. When lightning strikes near at hand, the thunder is one terrific deafening crash. At a distance it takes on a rolling character,

as the reports are heard in succession. If increased to fifteen miles, the discharge is no longer heard though the flash is seen.

821. Return Shock is experienced by persons at a distance from the locality where lightning strikes. It is a result of induction. They are charged with induced electricity of the opposite sign to that of the cloud; when the latter is discharged induction ceases, and the persons reverting rapidly from the charged to a neutral state the return shock is the result.

It is less violent than the direct, yet many cases might be cited in which it has killed men and animals.

822. The Lightning-rod was invented by Franklin, in 1755. It consists of a copper or iron rod, which passes the electricity from the ground to the excited cloud, uniting the two in a harmless manner. The essentials in a rod are:

1st. The terminal point must be perfect.

To secure this, the points should be platinized or gilt to protect them from the action of damp air.

2d. Projection to a sufficient distance.

The rod should project from six to ten feet above the adjacent parts of the building. It must also offer a perfect metallic communication from point to termination in the earth. Its section should be at least half an inch square, so it will not melt if lightning discharges upon it.

3d. Connection with extended metallic surfaces.

All metallic objects of any extent in the building must be connected with it, otherwise there is danger of lateral discharges.

4th. Perfect communication with wet earth below.

There should be the most complete communication between the rod and wet earth. It must never terminate under a verandah or piazza, but in the country it is better to lead it to a well, spring, or some other permanently wet spot. If no such place is near by, a hole six or seven yards deep may be dug, and the conductor divided into three or four strips and led into it, and the space filled with powdered coke. In the city it can communicate with the water pipes.

823. Aurora-borealis, or northern lights, is an electric phenomenon, sometimes of great beauty, seen at either pole. It consists of streamers or bars of light, which in the finest displays constitute a complete cupola. These are agitated by an undulatory movement, and from time to time exhibit great variations in brilliancy. Convergence of the streamers is to a point indicated by the northern end of the dipping needle in the northern hemisphere. Their color varies through red, green, and yellow.

In north polar regions, 150 auroras were observed in 200 days, nights without one were an exception to the rule. Their extent is sometimes wonderful, the same display having been observed at Moscow, Warsaw, Rome, and Cadiz. Their height is from 90 to 460 miles.

Their action on the magnetic needle proves that they are due to electric currents in the higher regions. They frequently interfere seriously with the working of telegraphs. Their spectrum gives five lines in the green, a faint one in the blue, and a red; these are probably due to nitrogen.

SECTION IX.

DYNAMIC ELECTRICITY.

CHAPTER XLV.

THE VOLTAIC CELL.

Electrodynamics defined—First observations—Volta's pile—Origin of voltaic electricity—The simple cell—The electric current—Electromotive force—Quantity and intensity—Enfeeblement and local action.

824. Electrodynamics Defined.—Machine electricity, which has thus far been the subject of our study, is electricity in the static state or condition of rest. It is that of tension. To understand more clearly its nature and the difference between it and the form we are about to examine, it is convenient that we regard it as a fluid according to the original hypothesis. As we study fluids first in their stationary condition under the science of hydrostatics, and afterwards in movement, as hydrodynamics, so with electricity, we may examine it first in the *electrostatic*, and then in the *electrodynamic*, or condition of movement.

825. First Observations.—In 1750 Sulzer observed, that if two metals were placed, one on the tongue and the other beneath it, when portions projecting from the mouth were touched to each other, a strong metallic taste was perceived. If one was placed upon the conjunctiva, and the other upon the tongue, and then brought together, a brilliant flash of light was seen. These results were attributed to a development of electricity.

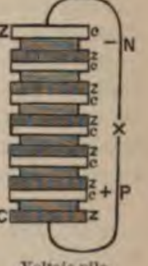
In 1770, Galvani made his famous experiment with frogs' legs. At the time, he was studying the effect of atmospheric electricity upon these animals. For this purpose he had attached a pair of legs by a copper hook to an iron balcony. Each time that the wind pushed them against the iron violent contractions were produced. A further examination of the phenomena showed, that when communication was made between a nerve and a

muscle by a single metal, contraction of the latter followed. If made by two metals, as zinc and copper twisted together at one end, and the other ends applied, one to the nerve, the other to the muscle, the contractions were more violent. Galvani explained the phenomena upon the hypothesis of two electricities, one in the muscle, the other in the nerve, and regarded the metal as acting the part of a discharging rod.

Close upon this came the experiment of Volta, who believed that electricity was the result of contact between two metals. Though Volta was mistaken as regards its origin, his work was of great value, since it resulted in the production of Volta's pile, which was the first electric battery.

826. Volta's Pile.—In this the principle of an increase in intensity of the electric disturbance by an additional number of elements is recognized. The apparatus consists of several disks of zinc, cloth wet with sulphuric acid, and copper. These are built up in a vertical pile, beginning at C, in the order zinc, cloth, copper, zinc, cloth, copper, the substances being laid on in that series until a pile of thirty to fifty sets is made. Wires are then attached, one to C at the lower end, and the other to Z at the upper. Through these the effects are transmitted; they are called *poles*, *polar wires*, *terminals* and *electrodes*. In ordinary batteries that connected with the copper, or platinum element, is called the *anode*, *positive*, +, *copper*, or *platinum* pole. That to the zinc, the *cathode*, *negative*, *minus*, —, or *zinc* pole. *In the arrangement*, *Fig.* 339, *the terminal metals really act as collectors. Their character in this respect, therefore, is reversed.*

FIG. 339.



Voltaic pile.

When the polar wires are brought in communication then separated, a minute spark is seen, which in all respects except that of size is a perfect counterpart of the machine spark. The snapping sound is also heard when contact is broken. If examined by the gold-leaf electroscope the leaves are repelled. In all respects, therefore, this resembles the ordinary machine electricity, except in its tension, or the distance through which it can strike from one conductor or polar wire to another.

Bodies which convey machine electricity well are good conveyors of this form; those which conduct it poorly are likewise poor conductors for this variety.

To electricity produced by Volta's pile the name of Voltaic is given. Since Galvani had antedated him in his observations on its character his admirers called it Galvanic. It is also known as battery and primary.

827. Origin of Voltaic Electricity is in chemical action generally between a solid and fluid, in which the former is attacked or dissolved. It has been amply demonstrated by Becquerel, Faraday and many others, that when this is initiated, and while it lasts, there is development of electricity; when it ceases, the electricity ceases. Many experiments might be advanced in support of this hypothesis, among them we cite the following:

1st. Take a plate of pure zinc to which a polar wire is attached, also one of platinum with its polar wire. Plunge the two in a vessel containing dilute sulphuric acid (water 20, acid 1), keeping them at a distance from each other. While they continue apart there is no chemical action on either. Now let the polar wires touch, and it at once begins. The zinc slowly dissolves, and hydrogen gas escapes from the surface of platinum. Separate them, an electric spark is seen, and at once all action ceases.

The establishment of a communication between the two metals of a battery is called *closing the circuit;* the opposite act, breaking or *opening it.*

2d. Solder two golden wires to the extremities of a conductor and plunge it into nitric acid, which does not act on gold: there is no electric action. Now pour hydrochloric acid into the vessel: the gold is at once acted upon by the aqua regia, and a current is produced.

828. The Simple Cell.—In the construction of galvanic batteries it is not easy to procure pure zinc. The ordinary zinc of commerce is acted on by dilute sulphuric acid. This difficulty is surmounted by using that which has been amalgamated, or bears a coating of mercury.

FIG. 340.

Simple cell.

Amalgamation of zinc. Cleanse the surface thoroughly with dilute sulphuric acid (one of acid to ten or fifteen of water). When perfectly clean pour mercury over it, this at once unites with it, and gives a clean, brilliant, metallic coating. If there are any spots which do not coat well, the action may be hastened by friction and fresh application of acid. Amalgamating fluids are recommended, but they evolve an irritating odor in their use. If the process we have described is properly managed, it can be accomplished very quickly.

The zinc having been amalgamated, it is attached to a wire by means of an arrangement of binding screws, and set in a glass vessel that is to contain the fluid with which the cell is to be charged. A plate of copper the same size as the zinc,

with a wire attached by a binding screw, is then placed in the cell. Dilute sulphuric acid (1 of acid to 15 or 20 of water) is poured into the vessel.

While the circuit is not established there is no action, but when it is closed there is electric disturbance, the zinc being dissolved, and hydrogen escaping from the copper surface. At the first moment of closing the electric action is very strong, but it instantly falls very low, owing to formation of bubbles of hydrogen on the copper, which reduce enormously the extent of contact between that metal and the fluid, and cut down the chemical action in proportion.

To avoid this reduction by gas formed on the copper various devices are resorted to, among them is the use of double fluid batteries.

829. The Electric Current.—So long as chemical action continues, and the circuit is closed, there is a continuous flow of electricity through the wire connecting the two metals. Therefore, it is called dynamic, in contradistinction to the static variety. The tension of this current is, moreover, exceedingly feeble, which is an essential difference between this and machine electricity.

It is not necessary that one of the metals should not be acted upon at all by the liquid, only that one should be more susceptible than the other.

The metal upon which the action is most energetic is the generating plate, or metal of higher *potential;* the other the collecting, or plate of lower potential. Direction of the current is determined by the positive metal. The current commences on it, passes through the liquid to the negative plate, thence by the polar wire to the positive, completing the circuit. Its direction is always in relation to the positive electricity.

Voltaic electricity arises whenever two metals are placed in a liquid which acts more strongly on one than on the other. They have, therefore, been arranged in tables, which express their relations to each other in this respect. These are called *electromotive series.* The electropositive are at one end, the electronegative at the other, the intermediate being arranged according to their relative value. Any two of the following metals placed in dilute acid, the current will pass from the lower to the higher. Iron, for example, is electronegative to zinc and electropositive to silver.

1. Zinc.	5. Iron.	10. Silver.
2. Cadmium.	6. Nickel.	11. Gold.
3. Tin.	7. Bismuth.	12. Platinum.
4. Lead.	8. Antimony.	13. Graphite.
	9. Copper.	

830. Electromotive Force is that by virtue of which electric effects are produced in a circuit, consisting of a liquid and two metals acting unequally upon it. The electromotive force is greater in proportion as the metals are distant from each other in the series. Indeed, it is the sum of the electromotive forces between all the intervening metals. Condition of the metal influences it; rolled zinc is negative to cast zinc. Concentration of the liquid, and its nature also have their influence.

The following table exhibits the effects of different solutions:

Caustic potassium.	Hydrochloric acid.	Sulphide of potassium.
Zinc.	Zinc.	Zinc.
Tin.	Cadmium.	Copper.
Cadmium.	Tin.	Cadmium.
Antimony.	Lead.	Tin.
Lead.	Iron.	Silver.
Bismuth.	Copper.	Antimony.
Iron.	Bismuth.	Lead.
Copper.	Nickel.	Bismuth.
Nickel.	Silver.	Nickel.
Silver.	Antimony.	Iron.

831. Quantity and Intensity.—The larger the size of the metal plates employed, the greater the quantity of electricity developed. In Hare's deflagrator very extensive surfaces of copper and zinc were used, the action of which when they were suddenly immersed in acidulated water was so great, as instantly to dissipate polar wires of small diameter. Tension or intensity, on the other hand, depends upon the number of cells or cups in the circuit. The greater their number the more intense the tension, until with batteries of five hundred an electric arc of several inches length is obtained. For ordinary purposes fifty make a very serviceable battery.

832. Enfeeblement and Local Action.—The principal causes of decrease in the action of a battery, are: 1st. Gradual neutralization of the acid and its conversion into sulphate of zinc. This is remedied by addition of acid. 2d. Formation of small closed circuits on the zinc, whereby it is corroded without yielding anything to the current traversing the polar wires. This is called *local action;* it is rectified by reamalgamating the zinc. 3d. Formation of a layer of hydrogen on the copper plate, reducing contact between the copper and liquid. This is called polarization of the plate. 4th. Hydrogen reacting on the zinc sulphate formed in the solution causes it to be precipitated upon the copper, hence, in place of having two metals with different relations to the liquid, this lessens, and in extreme cases is entirely lost. 5th. Production of inverse electromotive action, which either partially or entirely neutralizing the original current.

CHAPTER XLVI.

BATTERIES AND THEIR PHYSICAL EFFECTS.

Single fluid batteries—Double fluid batteries—Care of batteries—Measurements of electricity—Methods of coupling—Dry piles—Faure's accumulator—The spark—The arc—Ignition effects—Deflagration.

833. Single Fluid Batteries.—*Cruikshank's* consists of a wooden trough separated into cells by plates of copper and zinc soldered together. These are filled with dilute sulphuric acid (1 of acid to 15 or 20 of water). By inclining the trough on one side, the fluid can be passed along the edge and the cells all filled to the same level, with least loss of time. Polar wires are then attached to the metals at the ends.

Wollaston's. Liquid, dilute sulphuric acid, is placed in separate jars. Each is provided with copper and zinc elements. These are double-coppered—that is, the copper is bent to be opposite both sides of the amalgamated zinc surface. The metals are then attached to a frame, so they can be simultaneously lowered into the jars of acid.

Smee's. Liquid, dilute sulphuric acid. Metals, amalgamated zinc and platinum, or platinized silver, to favor escape of hydrogen.

Walker's. Liquid, dilute sulphuric acid; elements, amalgamated zinc and platinized carbon: is equal to the Smee, and cheaper.

Simple cupric sulphate. Liquid, strong solution of cupric sulphate; metals, non-amalgamated zinc and copper.

FIG. 341.

Grenet battery.

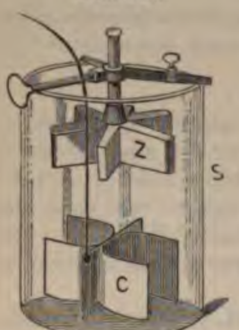
Grenet or bichromate. Liquid, electropoion, L, which consists of sulphuric acid and potassium bichromate, each one pound, water twenty pounds. Elements, amalgamated zinc, Z, and carbon, C. Fig. 341. The former should be raised out of the liquid by the button B, when not in use. This is the ordinary battery now supplied with small magnetoelectric coils for medical purposes. It has great electromotive force, and resistance is small. If air is blown through the cells, or if the fluid or elements are agitated, action is improved.

Leclanché. Liquid, saturated solution of ammonium chloride. Electropositive metal, amalgamated zinc. Electronegative ele-

ment, a porous cell occupied by a carbon plate, the remainder being filled with oxide of manganese, in coarse powder, and small pieces of gas carbon. Works a long time, requires water to make up loss by evaporation.

Colland's gravity. Elements, a plate of copper, C, Fig. 342, connected to an insulated wire. This is placed in the bottom of a jar, and covered with crystals of cupric sulphate. The jar is then filled with water, and the zinc element, Z, suspended therein. The zinc sulphate which forms floats on the surface of the cupric sulphate, S. Is very constant if loss by evaporation is replaced.

FIG. 342.



Colland's gravity battery.

Pulvermacher's chain consists of small cylinders of wood on which zinc and copper wires are spirally coiled, each being insulated from its neighbor. It is thrown into action by dipping into acidulated water. Is not constant.

834. Double Fluid Batteries. — *Daniell's.* Elements, amalgamated zinc, Z, and copper, C. Fig. 343. A glass cell containing saturated cupric sulphate, S. Inside of the copper cylinder fits a porous cell containing sulphuric acid, A, and into this the zinc, Z, dips. Is very constant. Serves as a standard.

FIG. 343.

Daniell's cell.

FIG. 344.

Grove's cell.

Mendinger's. Elements, amalgamated zinc and copper. Strong solution of magnesium sulphate containing the zinc, and crystals of cupric sulphate cover the copper. No porous cell, is a gravity battery and very constant.

Grove's. Elements, amalgamated zinc and platinum. Dilute sulphuric acid is placed in a glass cup, S, Fig. 344, in this the

zinc, Z, is put; then a porous earthenware jar, N, filled with nitric acid into which the platinum, P, of the next cell dips.

Tyndall's. Elements as in the last, and fluids the same. In place of glass, rectangular cups of rubber; the porous cells the same shape, and only half an inch wide. Has great power, and well adapted for lecture-room experiments. Packs into small space.

Bunsen's. Elements, amalgamated zinc and carbon. Vessels, a glass jar and porous cup. Liquids, dilute sulphuric and strong nitric acid.

Bichromate. Same as Bunsen's, but charged with electropoion in place of nitric acid.

835. Care of Batteries.—In those only used at considerable intervals, the porous cups must be well cleansed before they are put away. Soaking for two or three days in water, changed three or four times, suffices. If this is not done, they deteriorate very rapidly, and their usefulness is impaired. Forms in which carbon is employed should also be carefully cleaned, the carbon remaining in water for three days, and the latter repeatedly changed. By attending to the cleansing of a battery, it can be used for many years, otherwise it is soon destroyed.

836. Measurements of Electricity.—The following table represents the electromotive force of some of the ordinary batteries in use. The unit of comparison is a Daniell's cell:

Daniell's element	1.00
Leclanché's "	1.32
Bunsen's "	1.77
Grove's "	1.82

The greatest electromotive force was obtained by Beetz from elements consisting of potassium amalgam in caustic potash, with manganese dioxide in solution of potassium permanganate. It possessed three times the strength of the Daniell.

The standard of electromotive force is the *Volt*, it is a little less than that of a Daniell's cell, which may be taken as 1.12 Volt.

The unit of current is a *Weber*, which is equal to an electromotive force of one Volt working through an Ohm, the unit of resistance.

The *Ohm* is the famous B. A. (*British Association*) unit, and is represented by a column of mercury 104.81 centimetres long, one square millimetre in section, maintained at a temperature of 0° Cent.

837. Methods of Coupling.—Cells may be coupled for quantity or intensity. Suppose a battery of 40 cups, and it is desired to get the largest quantity therefrom. All the zincs would be

united for one pole, and the carbons for the opposite. The intensity would be that of a single cell, but the quantity equal to 40. Now, if required to obtain the greatest intensity, the cells would be coupled alternately; in a Grove battery it would be zinc, sulphuric acid, nitric acid, platinum; zinc, sulphuric acid, nitric acid, platinum, and so on for 40 variations. In this case the theoretical value of the result would be quantity 1, intensity 40.

Again, a battery might be coupled in two series of twenty each, giving quantity 2, intensity 20; or four, giving quantity 4, intensity 10; or the opposite, viz., quantity 10, intensity 4.

It is understood that full values are never obtained in practice, resistance and other causes reducing them materially.

838. Dry Piles.—In these, paper replaces the liquid of a battery. That of Zamboni consists of paper coated with tin on one side, and binoxide of manganese on the other, and cut into disks half an inch in diameter. One or two thousand are packed away in a glass tube with the tin of one always in contact with the manganese of the next. The tube has a knob and rod at each end, one of the latter has a screw thread cut on its surface, and is used to press the disks together. The manganese is the positive, the tin the negative, element.

Dry piles sometimes retain their power for years, it is the result of slow oxidation of the metals.

839. Faure's Accumulator consists of two strips of sheet lead about seven inches wide and several feet in length. These are coated with red lead, covered with canton flannel, and bent backwards and forwards in contact with each other, and packed in a lead-lined box. They are close together, but there is no metallic contact between them, the canton flannel acting as the insulator. The box is charged with dilute sulphuric acid, and its polar terminations brought in connection with a dynamo-electric machine. After some hours of action the Faure's cell is stored. If it is now separated from the dynamo, and its poles used in the same manner as those of any ordinary battery, it gives out its electricity gradually.

Under the title of storage batteries or accumulators, the Faure's cells are coming into general use for many purposes.

840. The Spark.—Use a Grove battery of six cells, coupled alternately for intensity, with copper poles.

The poles are touched, on separating them the voltaic spark is seen. It is a green color, owing to the presence of copper.

If the current is weak from a smaller battery, the discharge is seen better by bringing one pole in communication with one

›f a file, and drawing the other rapidly over its surface, a : appears as contact is made and broken.

tablish connection between mercury and one pole, with the make and break contact, a spark appears each time of ‹age.

. **The Arc.**—Use fifty cells of a Grove battery coupled for sity. Between two terminals of carbon when touched is produced which con- s when the poles are separ- for a short distance, de- ing on the strength of the ry. The continuous pas- of electricity between the ›ns is called the arc. The is exceedingly intense. If flame intervenes between ›rc and a screen, it casts a ›w thereon. The unbroken from one pole to the other ›nstrates its dynamic char-

FIG. 345.

Arc between carbon points.

ıce the carbon terminals r water in a glass globe, establish communication the battery. At once the s seen, though somewhat ıished in brilliancy.

ırious contrivances, called ators, are used to keep the nce between the carbon rodes such that the current ›ridge it over. The light ›quently shows a wavering ıcter, very trying to the By recent improvement ynamo machines, electric s of many thousands can- brilliancy are obtained.

. **Ignition Effects.**—Pass the ınt along a slender plati- wire, it is immediately l to a bright white heat, 'n as incandescence. If the current is sufficiently strong, 'used. This is the principle involved in the Edison light. ıuires much less intensity than the arc. It is, therefore,

less dangerous. As platinum undergoes a change by the passage of the current, Edison prepares it by slow heating in vacuo.

The carbon incandescent light consists of a U-shaped filament of carbon cut from a card and charred. It is enclosed in a small glass vessel which is vacuous. The passage of the current gives a very satisfactory light. The difficulty of obtaining material yielding a carbon perfectly homogeneous, has been surmounted by evaporating collodion in shallow vessels, passing the residue between steel rollers, cutting the product thus obtained in the proper form, and carbonizing it without access of air.

843. Deflagration.—If one of the poles of a battery consists of a cup-like cavity in gas carbon, and in this sodium or potassium is placed, on bringing a pointed pole to bear thereon, the metal is fused and volatilized. In this manner, the most refractory may be deflagrated or driven off in vapor. Gold is volatilized without difficulty, and metals held in the escaping vapor are gilded.

Metals used as terminals are also volatilized in the arc of electricity which passes from pole to pole. If submitted to examination by the spectroscope, the lines characteristic of the spectrum of each are seen. By comparing these with the reversed lines of the solar spectrum, the presence of the different metals in the atmosphere of the sun has been demonstrated.

Magnetic effects produced by the voltaic current will be discussed under the head of electromagnetism.

CHAPTER XLVII.

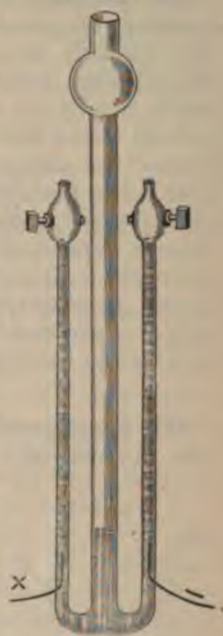
VOLTAIC DECOMPOSITIONS.

Decomposition of water—The voltameter—Decomposition of cupric sulphate—Decomposition of sodium chloride—Electrochemical theory—Polarization of electrodes—Electrometallurgy—Electroplating.

844. Decomposition of Water.—Two English chemists were attempting to determine the conducting power of various substances. Among liquids the first they experimented with was water. They had enclosed it in a tube the ends closed by corks through which the polar wires of a battery passed. These could

be approached nearer to, or drawn further from each other. The wires were of copper, and they expected to determine the effect of intervening columns of various lengths of liquid between the polar terminations. The apparatus being in order, and connections made with the battery, they found to their surprise that at one pole gas was evolved, while at the other a pale blue material gradually accumulated in the lower part of the tube. Various explanations were given of the phenomena, at last its true nature was revealed by analysis. The blue material proved to be hydrated oxide of copper. They had, therefore, decomposed water, which up to that time was supposed an elementary body, and had separated it into hydrogen and oxygen; the former was set free in the gaseous state while the latter with the copper had formed a hydrate of copper.

Fig. 346.



Decomposition of water.

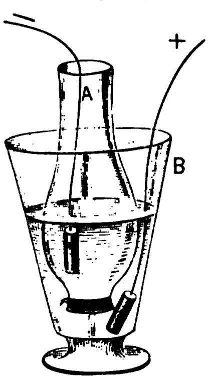
Improvements in the apparatus soon substantiated the truth of this explanation, for bending a tube into a U form, and allowing the battery to terminate in platinum poles, + and —, Fig. 346, which are not acted on by water, one in each arm, gas was evolved from both poles. At one hydrogen, at the other pure oxygen. The quantities, moreover, bore a definite relation to each other. There was always twice as much of the former as the latter. It was, therefore, demonstrated that water is a compound body, formed of hydrogen and oxygen, in the proportion expressed by the formula H_2O.

845. The Voltameter.—Previous to the discovery of the compound character of water, many futile attempts had been made to test the value of electric currents, but no reliable method had been devised. The decomposition of water by strong currents of electricity was soon advanced as giving a satisfactory means of determining the value of such currents. The apparatus was called the Voltameter. It consisted of a tube graduated to cubic centimetres, or to cubic inches and fractions. Platinum or gold terminals of a battery passed through the bottom of a cup, and were arranged face to face in its interior, a moderate distance intervening between them. On establishing communication with a battery, gas was evolved from the terminals, and the time required to collect a given quantity of the mixed gases represented the power of the battery. This method still constitutes one means for obtaining the value of strong currents.

846. Decomposition of Cupric Sulphate.—Let the polar wires of a battery terminate in a strong solution of sulphate of copper. The cathode a conducting surface of any kind, the back and sides coated with any non-conducting material, as wax. The anode a plate of copper. A current of suitable strength from a small Smee battery is then passed through the liquid. After a time the cathode is removed, when it will be found coated over with metallic copper, if the strength of the battery has been properly adjusted. The action of the current has been to cause a deposit of copper on the cathode. As fast as this takes place the sulphuric acid disengaged upon the anode attacks it, and restores the metal to the solution. This conveyance of copper from anode to cathode continues as long as the former lasts or the battery retains sufficient power.

847. Decomposition of Sodium Chloride.—Take a vessel shaped like the chimney of a kerosene lamp, A, Fig. 347. Close the lower mouth with a layer of goldbeater's skin, tying it on firmly. Prepare a tolerably strong solution of sodium chloride, add to it sufficient red litmus water to give it a strong tint. Pour half into the vessel, let it rest in a goblet, B, and pour the other half into this. Pass into the former the platinum terminal of the cathode; into the latter plunge the anode. Make connection with the battery. Gas bubbles appear at both poles, but the liquids are prevented from intermingling by the intervening septum of goldbeater's skin. At the cathode sodium is set free, which instantly attacking the water becomes converted into sodium oxide, and its alkaline reaction is exhibited by turning the red litmus blue. At the anode chlorine is evolved, as shown by bleaching of the litmus. The sodium chloride has, therefore, undergone decomposition, the sodium appearing at the cathode, and the chlorine at the anode.

Fig. 347.



Sodium chloride decomposed.

848. Electrochemical Theory.—A number of illustrations of this, so-called, *sliding decomposition* might be given. We may, however, sum up the results in a table, as follows:

To anode or + pole.	To cathode or — pole.
Oxygen.	Hydrogen.
Chlorine, bromine, etc.	Metals.
Acids.	Bases.
Electronegatives.	Electropositives.

The bodies attracted by the anode or positive pole are electronegatives. Those attracted to the cathode or negative pole are electropositives. It is understood that the terms electronegative and electropositive are relative, and refer to the relation of the two substances under the conditions which they are submitted to examination.

To this decomposition by electric action the name of *electrolysis* is given. The bodies subjected to the action of the current are called *electrolytes*. The substance which appears at the cathode is called the *kation*, that at the anode the *anion*.

849. Polarization of Electrodes.—Let a current pass from platinum electrodes through water for a time. Interrupt it, and connect the electrodes with a galvanometer. They will be found to give a tolerably strong flow of electricity which passes in the opposite direction to that of the battery. The explanation lies in the fact, that oxygen has been condensed on the anode, and hydrogen on the cathode. The effect of this is to produce a current opposed in its action to the original.

On this principle batteries of one element may be constructed, consisting of platinum poles separated by moistened cloth. These are connected with a battery and charged. They are then separated, and being attached to a galvanometer, give a current in the opposite direction to the original. They are called secondary batteries. Plante's battery, which was the original of Faure's accumulator, is of this description.

850. Electrometallurgy, or galvanoplastics, is the application of voltaic electricity to copying medals, type, and other objects. The operation consists first, in securing an accurate mould of the object, upon which copper or some other metal can be deposited by an electric current. Various methods are resorted to for making the cast. One consists in softening gutta-percha in water, pressing it against the object, and, when cold, detaching it. The process usually employed is that followed in *electrotyping*. A mixture of wax, tallow, and turpentine, of proper proportions, is melted and poured into shallow pans. When set, it is brushed over with finely powdered graphite. While still soft the form of type is pressed on its surface, and an accurate copy obtained. This is suspended from the negative pole of a battery in a solution of copper, a plate of the same metal being attached to the positive pole, when a deposit forms on the cast.

The batteries employed are usually either Daniell's or Smee's. Currents from magnetoelectric machines of special construction are used when a large amount of work is to be done.

In all such operations a number of conditions govern the

character of the deposit. Among them, the power of the current of the battery, the strength of the solution used for electrotyping, and its temperature. If the conditions are correct, a tenacious, flexible metallic, or *reguline*, deposit is obtained. If the current is too strong, the deposit becomes pulverulent and black; if too weak, it is brittle and crystalline. The object of the electrometallurgist is to adjust them to obtain the reguline deposit.

The application of this principle to the preparation of forms for printing, makes the issuing of enormous editions of the great daily papers possible in the few hours available for that purpose. The type is set and corrected, a number of impressions of these forms in wax are then taken, they are electroplated. The electroplates, each a perfect copy of the original, are separated from the wax, and melted metal poured into them. All are reduced to a uniform thickness, and mounted in a printing machine. Thus, in place of printing from a single form, ten, fifty, or even a hundred sets of copies of the original are all doing work at the same time.

851. Electroplating differs from the preceding in that it is an exceedingly thin deposit of gold, silver, iron, nickel, or other metal on the surface of some composition or alloy. The preparation of the objects is usually by two stages: 1st. The fatty matter, with which their surfaces are covered, is destroyed by heat. 2d. The oxide formed in the preceding operation is removed by immersion while still hot in very dilute nitric acid. They are then rubbed with a hard brush in pure water, dried in hot sawdust, and attached to the negative pole of a battery, the positive bearing a plate of gold in the solution.

There is considerable variety in the composition of the solutions or electrobaths for gilding. The ordinary one is:

Auric chloride	1 part.
Potassium cyanide	10 parts.
Water	200 "

In electrosilvering the composition of the bath is as follows:

Argentic cyanide	2 parts.
Potassium cyanide	2 "
Water	250 "

A plate of silver or gold is suspended from the positive electrode, the properly cleansed articles from the negative.

The bath for deposition of iron is prepared by attaching a large sheet of iron to the positive pole in a vessel filled with saturated solution of ammonium chloride. A small strip of iron is attached to the negative pole. The current being

passed, it is dissolved, while hydrogen escapes from the small negative element. When the bath is changed an engraved plate of copper may be substituted for the small strip of iron, a bright deposit forms at once, the plate taking on the appearance of polished steel. The process is called *steeling the acierage*. In the course of half an hour it is sufficiently thick, and of exceeding hardness, an immense number of impressions can be struck off.

The bath for nickel is prepared in the same manner, or by directly mixing salts of ammonia and nickel, either chloride or sulphate of the metal with chloride of ammonium. The deposit tends to form irregularly and strip off. This is counteracted by repeatedly removing it, repolishing it, and returning it.

Nickelplating is now extensively resorted to for coating surfaces of all kinds of surgical and obstetrical instruments and apparatus. It resists ordinary corrosives, and air has no action upon it.

CHAPTER XLVIII.

THERMOELECTRICITY.

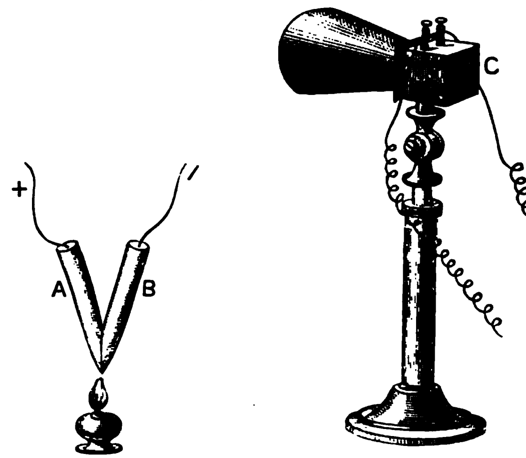
Heat in obstructed conductors—Thermoelectric batteries—Thermoelectric series—Other batteries.

852. Heat in Obstructed Conductors.—When a current of electricity is passed along a conductor of too small a section to permit its free transit, the temperature of the latter rises, and it may fuse though composed of the most refractory metal. The converse of this is also true: if we warm a conductor along which heat fails to pass freely, by virtue of a strain upon its molecules, electricity is developed which is readily detected by a galvanometer.

In illustration, take a copper wire and tie a knot in it, to strain or put tension upon its molecules. Connect its ends with the pole of a galvanometer, then apply a spirit flame near the knot. The torsion of the wire affords an obstacle to the passage of heat, and the needle of the galvanometer shows an instantaneous movement from the electricity developed. To this the name of thermoelectricity is given.

853. Thermoelectric Batteries. — While only a single metal may be forced to show thermoelectric properties, the phenomena are much better developed where two are used. Take, for example, a small bar of antimony, A, and one of bismuth, B, solder them together as in Fig. 348. To the free extremities connect polar wires, by which the apparatus may be attached to the galvanometer. Connect it and apply cold to the junction of the two metals, the needle at once shows the production of

FIG. 348.



Thermopile.

a current. Apply heat thereto, and the swing of the needle is reversed, showing that direction of the current is changed.

A number of such elements, of antimony and bismuth soldered together at their alternate ends, the order of alternation being carefully preserved, and the bars being insulated elsewhere, constitutes a thermoelectric battery. The number of pairs increases the intensity of the current. The ordinary number is forty-nine, arranged in seven rows of seven. This gives an end-section about an inch square, C, and is known as Nobili's thermoelectric pile. In connection with a galvanometer it forms the thermoelectric multiplier of Melloni, which is one of our most delicate instruments for measurement of temperature.

854. Thermoelectric Series. — After many experiments, the thermoelectric relations of various substances to each other were carefully determined, and are set forth in the following table. The value of any pair may be found by subtracting the figures

from each other, if they have the same sign, or adding them if the signs are different:

Bismuth	+25	Gas coke	—0.1
Cobalt	9	Zinc	0.2
Potassium	5.5	Cadmium	0.3
Nickel	5	Strontium	2.0
Sodium	3	Arsenic	3.8
Lead	1.03	Iron	5.2
Tin	1	Red phosphorus	9.6
Copper	1	Antimony	9.8
Platinum	0.7	Tellurium	179.9
Silver	1.0	Selenium	290.0

Compared with hydroelectric currents, these are quite feeble. The electromotive force of a bismuth copper element with a difference of 100° C. in the temperature of their junctions, is, according to one authority $\frac{1}{95}$, and to another $\frac{1}{256}$, that of a Daniell's element.

855. Other Batteries.—Becquerel discovered that artificial sulphide of copper combined with copper had an electromotive force nearly ten times as great as that of a bismuth copper pair. Since this sulphide only melts at over 1000°, very high temperatures may be employed.

Clamond's battery has been applied to telegraphing and plating. The negative metal is an alloy of two parts antimony, and one zinc. The positive a thin strip of tinplate. Heating is effected by a Bunsen flame, so applied that only the hot air from it touches the elements. The temperature should not rise above 200°.

SECTION X.

MAGNETISM.

CHAPTER XLIX.

HISTORY. LAWS. DISTRIBUTION.

Natural magnets—Artificial magnets—Compound magnets—Polarity law of attraction and repulsion—Magnetic distribution—Magnetic metals—Magnetic induction.

856. Natural Magnets were known in Europe more than 2000 years ago. The Chinese have used them since 600 B. C. They were portions of lodestone, native oxide of iron, having the composition Fe_3O_4. It was first found at Magnesia, in Asia Minor. A small portion freely suspended by a thread, sets itself with its long axis north and south. It is, as a rule, very free from admixture with other minerals, and when smelted yields a remarkably pure iron.

While we mark the north end, the Chinese mark the south end. They used magnets as iron needles to guide them across the deserts of Asia. In French works the end pointing north is called the austral or southern pole; that south the boreal or northern pole. The English call that which points to the north, the north pole; to the south, the south pole.

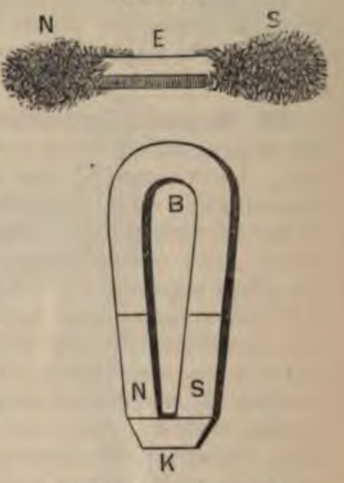
The awkward form of most native magnets makes them less advantageous for illustrating their properties than those which are artificial. We shall, therefore, pass at once to a description of the latter, and it is understood that their use is always implied unless otherwise stated.

857. Artificial Magnets are either straight or horseshoe shaped bars of steel, which have been rubbed on natural or electro-magnets. If freely suspended, they point N. and S.

If placed in wrought-iron filings, Fig. 349, these arrange them-

selves in curved lines about both ends, N S, and not at all about the central regions, E. Hence, the two extremities are called the poles, and the central portions the neutral line. Sometimes a magnet will show intermediate poles between the true terminal ones. Such are abnormal.

Fig. 349.



Straight and horseshoe magnet.

The shortest line joining the two poles is called the axis of the magnet. The plane at right angles to this, and passing through the neutral line, is called the equator.

In a horseshoe magnet, Fig. 349, the axis is in the line of its keeper, K, or small piece of soft iron, in contact with the poles N S. The keeper should always remain in contact with the poles, as it reacts upon them, and enables the instrument to preserve its properties.

As a rule, the north pole is marked N., and the south S. In some the former is colored red, the latter blue; hence, the use of the terms red and blue magnetism, as equivalent for north and south.

858. Compound Magnets.—In place of making a magnet of a single piece, it is found that better effects are gained by combining a number of thin sheets of steel, Fig. 350, A, magnetizing each, and then binding them together by screws. For a given weight of metal a more powerful action is obtained.

Fig. 350.

Compound magnet.

This form, constructed as a horseshoe, is generally employed in various magnetoelectric instruments. From the nearness of its poles it gives a stronger result, and presents the advantage of the preservation of its power by the keeper B.

859. Polarity Law of Attraction and Repulsion.—It has been seen in the preceding article that soft iron filings are attracted by the magnet. If, for these, a small bar of soft iron is substituted, and presented to a freely suspended magnet, it will attract it equally by either extremity. If in place of the soft iron bar we use a magnetized steel one, its north pole will be found to attract the south pole needle, and repel its north pole.

Hence, we deduce the following law of the action of magnetic

poles on each other. Attention is directed to its similarity to the law of electric attractions and repulsions: *Unlike poles attract; like repel.*

The intervention of a sheet of glass between the bar of steel and the suspended needle in no way interferes with these movements. *The magnetic influence, therefore, passes freely through glass.*

860. Magnetic Distribution.—The magnetic influence in a steel bar is not confined to the extremities, but is distributed throughout. In evidence of this fact, let it be broken at the middle. Examination will show that each fragment is a true magnet endowed with perfect polarity. Freely suspended it points N. and S., one end attracts the north pole of a magnetic needle, the other repels it.

Break it again and again with the same result. We, therefore, conclude that the magnetic influence is distributed throughout the bar, and the neutral line, as it is called, is merely that portion in which the magnetisms neutralize each other. *According to theory, every molecule shows polarity.* The distribution may, therefore, be examined either in respect to the molecules, or to the whole bar as a system.

From the latter point of view, the poles are not at the extreme ends, but at a small distance within. They are not permanent, but change in position slightly whenever its condition is disturbed by the approach of a magnetic substance.

This is the principle upon which the telephone is founded.

861. Magnetic Metals.—These are iron, cobalt, and nickel. All bodies under the influence of exceedingly powerful magnets yield to their influence, but these, with magnetism of the ordinary intensity, exhibit magnetic properties—that is, are attracted, or show polarity.

A distinction is made between magnetic substances and magnets. The former attract either end of a suspended magnetic needle. The latter exhibit polar attractions and repulsions when brought in its vicinity and also of each other. Soft or wrought iron is an example of the former, a magnetized steel wire of the latter.

Many compounds of iron are magnetic bodies; some, however, are notable exceptions. The mineral limonite, an hydrated oxide of iron, does not show the property unless intensely heated on charcoal. Persulphide of iron is also non-magnetic until heated.

862. Magnetic Induction.—Bring a small cylinder of soft iron in contact with a bar magnet. It is attracted, and if in com-

munication with its north pole the end nearest to it takes on the opposite magnetic state, the further end becoming north. Thus bar after bar of soft iron may be attached until the limit of its power is reached, Fig. 351. Each piece shows polarity at

FIG. 351.

Magnetic induction.

its extremities. The near end is south magnetism, the further north. Separate the bars, and remove them from the influence of the magnet. At once all polarity is lost. They become inert, their magnetism was temporary.

CHAPTER L.

METHODS OF MAGNETIZING. TERRESTRIAL MAGNETISM.

Magnetizing by single touch—Magnetizing by separate touch—Magnetizing by double touch—Magnetizing by the earth's action—The power of magnets—Mayer's floating magnets—Medical application of magnets—The earth's action directive—Declination—The compass—Astatic needle—Dipping needle.

863. Magnetizing by Single Touch.—In this method one pole of a powerful magnet is passed from end to end over the bar. The operation is repeated a number of times. Its neutral condition

is thus decomposed throughout. The end last touched has the opposite polarity. For this operation, natural or artificial magnets and electromagnets are used. The disadvantage is that consequent or intermediate poles may be developed, and the power is not very strong.

864. Magnetizing by Separate Touch consists in taking two compound magnets of equal power, A B, Fig. 352, and placing their opposite poles upon the centre of the bar to be magnetized. They are then moved to the opposite ends, *a b*, at the same time and with the same rate. They are then returned to the centre,

FIG. 352.

Magnetizing steel bars.

and drawn to its opposite ends again. This operation is repeated a number of times, on both faces, until it is fully charged. The magnets by some are held vertically; by others, at an angle of twenty or twenty-five degrees. The method gives very regular results.

864 A. Magnetizing by Double Touch.—The two magnets are placed on the centre of the bar with their opposite poles nearly touching, a small piece of wood between them. They are then moved simultaneously to one end, then to the opposite. This is repeated a number of times, each half receiving the same number of movements over its surface.

The process may be improved in this and the preceding method by supporting the ends, *a b*, upon powerful magnets, A B, the pole on either side being of the same name as the movable magnet of that side. A horseshoe shape with close poles may be substituted for the movable pair. This is apt to develop consequent poles. The magnetism is very strong.

865. Magnetizing by the Earth's Action.—When a bar of soft or wrought iron is held in the magnetic meridian parallel to the inclination, it becomes immediately a temporary magnet, the lower being the north pole for our vicinity. Reversing it, the opposite end becomes the north pole. If, while held in the proper position, a few blows are struck with a hammer, it retains its magnetism for a short time. If it is twisted, only a feeble charge is developed.

Various articles of iron, both wrought and cast, if kept permanently in this position, acquire a certain amount of magnetism, the north pole always being downwards.

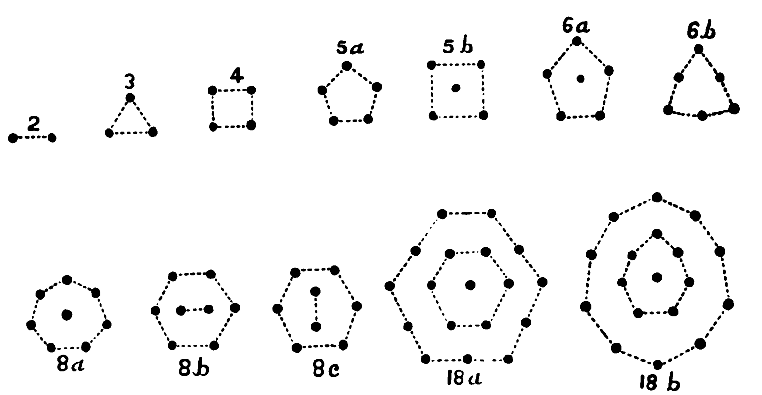
866. The Power of Magnets.—A magnet which has received its full development of force is said to be saturated. Among the causes which produce variation in strength, is tempering of the steel employed. A bar tempered at dull redness, and magnetized to saturation, made ten oscillations in ninety-three seconds. The same bar at a cherry red, took only sixty-three seconds to make ten oscillations. It, therefore, follows that the harder the steel the greater its coercive force. It is more difficult to magnetize, but it retains the charge better. The property of a magnet is also dependent upon the percentage of carbon contained in the steel. This also causes a variation in the degree of heat at which it should be tempered. Compass needles are generally tempered at a blue, which is about 300° C.

Increase of heat diminishes intensity of magnetism in a bar; heated to a bright red it completely loses it, and it is not regained with return to original temperature.

Hammering a steel bar while being magnetized increases its power. If, on the contrary, a magnet is allowed to fall, or struck a strong blow, it is in part demagnetized.

867. Mayer's Floating Magnets consist of magnetized steel needles, the points being north, and the eyes south poles.

FIG. 353.



Mayer's floating magnets.

These are passed through cork disks with the eyes just projecting. When placed on water they float, the needles being in the vertical position.

If a strong magnet is brought in the vicinity of several of these needles floating on water, they immediately arrange themselves in figures, which vary according to their number. Two form a line; three a triangle; four a square; five a pentagon, or a square with one in the centre; six a pentagon with one in the centre, or a triangle with curved sides, and so on. Through 8 a, b, c, 18 a and b, a shock will often cause one figure to pass into another more stable.

868. Medical Application of Magnets.—When the cornea has been wounded by minute particles of iron driven into its substance with considerable force, they are sometimes extracted with a magnet. There does not appear to be any evidence that they possess medicinal or other influence on the human body.

869. The Earth's Action Directive.—From observations made in various regions of the earth, it has been likened to an immense magnet, the poles not far from the terrestrial poles. The influence which it exerts upon the magnetic needle is directive only, it neither attracts nor repels it.

If a bar of steel is weighed before and after magnetization, there is no change. Therefore, the vertical component is zero. If suspended by a long fine thread, the course of the latter is vertical. If then magnetized, the thread remains the same. The horizontal component is, therefore, zero. Floated on a cork on water, the needle oscillates for a time, and finally sets itself N. and S., but does not move in a north direction. On the approach of a magnet, the needle moves toward it, but in the case of the earth it is equally attracted by both poles practically at an infinite distance; neither can exert greater power than the other, consequently it is not attracted, but merely sets itself in relation to their directive action.

870. Declination is the angle which the axis of a magnetic needle makes with the geographical meridian of a place. It is said to be east or west, according as its north pole is east or west of this meridian.

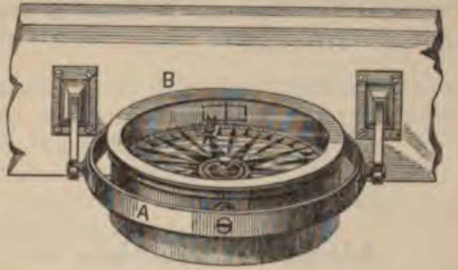
At present the declination is to the west in Europe and Africa, but to the east in Asia and North and South America. It shows variations either annual or diurnal, regular or irregular—the latter are called magnetic storms.

At London, in 1580, the declination was to the east 11° 36′, in 1663 it was at zero. Since then it has gradually moved to the west, reaching the maximum of 24° 41′ in 1818; thence slowly worked its way eastward, and in 1879 was at 18° 40′ west.

871. The Compass is a declination needle used in navigating ships. It consists of a case mounted A B, to keep the compass

in a horizontal position in spite of the ship's movements. From the bottom of the box a vertical axis rises, terminating above in a point which works in an agate cup attached to the centre of the needle, N. To the latter a disk of mica is attached, on which a star with thirty-two branches is traced. This gives the

FIG. 354.

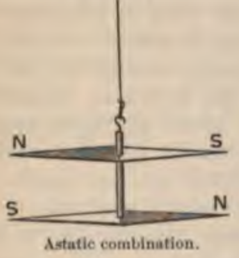


Compass.

eight points with halves and quarters. The ray marked with the small star and the letter N indicates the position of the north pole of the needle under the mica.

872. Astatic Needle.—This is a combination of two needles of the same strength, joined parallel to each other with their poles in opposite directions. A combination in this state is free to obey any other force, and is used in constructing a galvanometer.

FIG. 355.



Astatic combination.

FIG. 356.

Dipping needle.

873. Dipping Needle, also called the inclination compass. It moves in a vertical instead of horizontal plane. When this coincides with the magnetic meridian, the angle which it makes

with the horizon is called the *dip* or inclination. This differs in various parts of the earth. At the equator it is zero, the needle being horizontal, passing from the equator northward it increases, its north pole inclining downwards, until at the pole it is vertical. Passing southwards from the equator, its south pole dips downwards, until at that pole it is vertical.

The magnetic equator is the line which joins all places where there is no dip; it is sinuous, and inclined to the terrestrial at an angle of about twelve degrees.

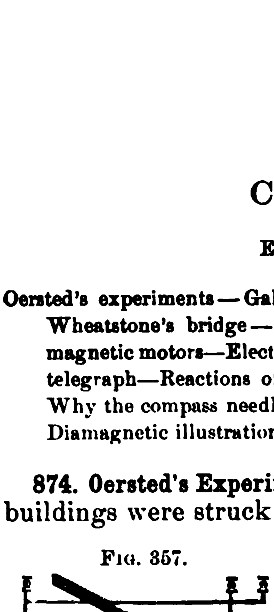
CHAPTER LI.

ELECTROMAGNETISM.

Oersted's experiments — Galvanometers — Rheostats — The long compensator — Wheatstone's bridge — Electromagnets — Electromagnetic motors — Cost of magnetic motors—Electric bells and clocks—The Morse telegraph—The needle telegraph—Reactions of currents upon currents and magnets—Solenoids—Why the compass needle points north — Paramagnetism — Diamagnetism — Diamagnetic illustrations—Action of magnet on polarized light.

874. Oersted's Experiments.—It had long been known that when buildings were struck by lightning, all small objects of steel or cast-iron contained therein showed more or less of a magnetic property. In 1819, Oersted, a Danish philosopher, submitted these phenomena to examination, and found, that if the wire in which a voltaic current is passing is placed over a freely suspended magnetic needle in the same vertical plane, the latter is instantly deflected, and sets itself at right angles to the current, its north pole, we will suppose, being turned to the east. If it is then placed beneath the needle in the same vertical plane, the current still passing in the same direction, it is also deflected, but now the north pole turns to the west.

FIG. 357.



Oersted's experiments.

If in place of using a straight wire, it is bent in the form of a rectangle, and placed in the same vertical plane as the needle, and surrounds it, when a current is sent through the conductor, in traversing the lower limb its direction is the reverse of what

it is in the upper. The action of the former, therefore, assists that of the latter, and the influence over the needle is increased. The stronger the current of voltaic electricity, the greater its effect. The nearer it is to the needle the greater the power it possesses over it.

By Oersted's discovery the intimate relationship between electricity and magnetism was established. This finally resulted in giving satisfactory explanations of the source of the latter, and why the compass points to the north.

875. Galvanometers.—If in place of passing the current around the needle once, we cause it to pass twenty or a hundred times, A, Fig. 358, its influence is increased, though not in the same proportion. This is the principle involved in the galvanometer, *multiplier*, or *rhéomètre*.

FIG. 358.

The galvanometer.

The delicacy of a galvanometer depends upon the facility with which its needle will turn. This is greater as the directive force of the earth upon it is diminished. Therefore, two with their poles reversed as in the *astatic system* are used. The directive force of the earth's magnetism is thus reduced to a very low point, and a feeble current will produce movement. The insulated wire is passed a number of times, A, around the lower needle of the system; it is usually wound around a flat spool of bone or ivory, with the lower needle in the interior and the upper above it. A current passed through this arrangement affects the former powerfully, and provides a very delicate instrument for the detection, not only of the presence of electric disturbance but its direction. The latter is varied by means of the *commutator*, which, by the turning of a button, changes the connections and consequently the course of the current.

Galvanometers are constructed either for measuring intensity or quantity. In the first case the current having considerable tension, the number of turns may be hundreds or thousands (that of Du Bois-Reymond made 27,000 turns), and the wire exceedingly fine. In the other, the wire must have a much greater diameter to give the least possible resistance, and make only a few turns around the needle. If beyond fifteen or twenty, the influence of the current on the needle is diminished.

The wire must be absolutely pure, and free from every trace of iron, otherwise it will interfere with the action of the current. The insulating material must be white silk, not green, as the latter contains iron.

The needles are suspended by a filament of silk, and the

whole arrangement protected from dust and currents in the air by a glass shade.

The *combination of a galvanometer with a thermoelectric pile* constitutes a very delicate means of measuring minute changes in temperature (853).

A *shunt*, by which the amount of current passing through is regulated, is usually supplied with each instrument.

In *Thomson's galvanometer* the needles are very small, and connected by a wire of aluminium astatically. This bears a slightly concave mirror about a quarter inch in diameter, needles and mirror weighing about one grain. The scale is placed horizontally about two or three feet distant. A slit below it, illuminated by a lamp, allows a narrow beam of light to fall upon the galvanometer mirror which reflects it back upon the scale, and thus gives accurate indications of the movements.

Wiedemann's boussole. In this a magnetized ring is suspended in the interior of a hollow thick cylinder of copper, an aluminium wire attached to it bears a mirror by which its movements are indicated. The coils through which the currents pass are arranged on each side of the copper chamber. The latter acts as a damper by reason of the currents set up in it by movements of the needle. By means of an accessory magnet the needle is made astatic. The advantage of this instrument is that the current slowly swings the needle to its maximum deflection, where it rests without oscillation.

Thomson's galvanometer and Wiedemann's boussole are provided with two coils, in which currents can be made to traverse in the same or opposite directions; in the latter case the results are differential—that is, two currents may be compared regarding their strength.

876. Rheostats are instruments for measurement of resistance to the electric current, and are essential in investigating problems in electrophysiology.

One of the simplest forms is *Wheatstone's rheostat.* It consists of two cylinders, one of brass, the other wood, with a similar spiral groove on each, carrying a fine brass wire forty yards long, arranged to wind from one cylinder to the other. The brass being a good and the wooden a bad conductor, the turns of wire on the latter are insulated from each other, and thus as more or less is wound thereon a varying and known resistance, corresponding to the number of turns therein, is introduced into the circuit.

When greater resistances are introduced the *resistance box* is employed. It consists of a series of bobbins of insulated wire, a greater or less number of which may be thrown into

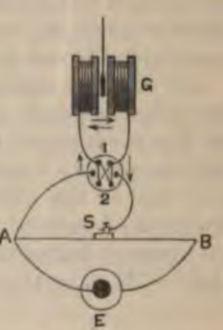
circuit by means of thick brass plugs. When all are in there is the least resistance, with all out the greatest.

For greater resistances, *tube rheostats* containing distilled water are used, the wires passing into it through stoppers at each end· A column of water one metre long and one millimetre in diameter, offers as much resistance to an electric current as a copper wire of the same diameter and long enough to make 167 turns around the earth.

For the following descriptions of the long compensator and Wheatstone's bridge we are indebted to Robertson's work.

877. The Long Compensator consists practically of a single uniform wire of brass two metres long, and 1.75 mm. in diameter. It is stretched on a piece of wood between two brass plates, fitted with binding screws, A and B. On it is a slider, S, which can be moved from one end to the other and makes contact all the way. It also carries a binding screw. From a constant element, E, a wire is led to A, and another to B. A key may be interposed on the way. From A and S wires are led to the side cups of the commutator which has the cross in, and from end cups they go to G, the galvanometer. Now, the current from E will pass to A, and may here branch into two circuits, the *long circuit* by the commutator to G, and back through it to S, then on to B and back to E; and the *short circuit* straight along the wire A B, and back to E. If the slider S is close to A, it is easy to see that all the current will be short-circuited, and none will go through the galvanometer. If, however, it is moved away, then a small amount will find its way through G, and this increases the further S is removed from A. In fact, the amount sent through G will be proportional to the distance A S. Thus its strength can be varied at pleasure, and measured. Further, it can be sent in either direction through G by means of the commutator. If this is down towards 1, it will pass in the direction of the continuous arrow; if towards 2, it will traverse G following the dotted arrow.

FIG. 359.

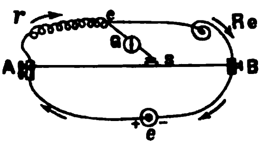


Long compensator.

878. Wheatstone's Bridge is shown in diagram in Fig. 360. At e is a Daniell's element; and A B is the platinum wire of a long compensator, of which s is the slider. From e the positive electrode goes to A, the negative to B. From A a wire passes to r, the body whose resistance is to be measured, from

which again a wire is carried to one binding screw of R e, a resistance box, from whose other binding screw a wire makes connection with the end B of the compensator wire. To the same binding screw c of the resistance box R e, by which r is connected with it, another wire leads to the galvanometer G, and the other terminal of G is attached to the slider s of the long compensator. When the current reaches A it will split into two branches, one passing along the long compensator to B, and the other to r, c, and R e. But at s and c these will also split, part of r c, R e, passing down to the galvanometer, part of A s, B, passing up to G. These two currents being in opposite directions, will deflect the needle in contrary ways. If one is in excess, it will deflect the needle in one direction; if the other, in the opposite; if both are equal, they neutralize one another, and it will remain at zero; or, to put it more accurately, when the potential at s is equal to that at c, no current will pass through the galvanometer.

FIG. 360.



Wheatstone's bridge.

As already explained, the strength of the current in the two branches depends on the resistances therein, and can be altered by the position of the slider s. Consequently, all that is necessary to secure equal potentials at c and s is to move the slider one way or the other, until the needle returns to zero, this indicating the desired equality. Now, it can be shown, that when no current traverses the galvanometer, the resistance of r is to that of R e, as the resistance of A s is to that of s B; thus:

$$r : R\,e :: A\,s : s\,B.$$

Put in another way, this is:

$$\frac{r}{R\,s} = \frac{A\,s}{s\,B},$$

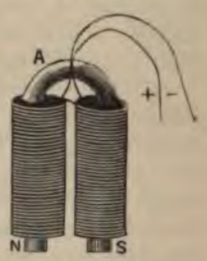
and, therefore,

$$r = R\,e \times \frac{A\,s}{s\,B}.$$

Now r is the resistance to be measured, R e is that in the box, which is read off at once according to the number of plugs out, and A s and s B are those of the lengths of the compensator wire on each side of the slider, which are also known. Thus, r, that to be measured, is given in terms of R e, A s, and s B, resistances that are known. The box is used, because by pulling out or inserting plugs its resistance can be varied at pleasure. According to that thrown in by it will be the position of the slider, and thus, by varying it, it becomes easier to adjust that properly.

879. Electromagnets.—If an insulated copper wire + — is wound in a helix around a rod of soft iron, A, and a voltaic current passed through the former, the core of the latter at once becomes powerfully magnetized. It attracts other masses of iron with far greater force than an ordinary magnet. It exhibits polarity, having a north and south pole, N S. Brought into the vicinity of others, or of electromagnets, it shows attraction and repulsion. The moment the current is broken, or opened, magnetism ceases. The instant it is closed it reappears in its original intensity. The magnetism is, therefore, the product of the action of the electric current upon the soft iron core, lasting while it lasts, ceasing when it ceases.

FIG. 361.



Electromagnet.

By bending the soft iron into the form of a horseshoe, as in ordinary artificial magnets, Fig. 361, and winding the wire to have it bear the same relation to the core as though straight, the approximation of the poles increases the magnetic effect. Care must be taken that there is no reversion in the winding, or the effect will be diminished in the same proportion.

Other things being equal, an increase in the number of turns up to a certain point, adds to the effect. After that, distance of the circuit becomes too great to affect the core, and increased resistance causes diminution.

The greater the diameter of the wire, the stronger the magnetism produced, especially with currents of feeble intensity.

The larger the elements of the battery the greater the magnetic effect. A sufficient number of elements to drive the current freely through the wire is, of course, essential.

The iron used should be as pure as possible, otherwise it will not gain and lose its magnetism suddenly with the closing and opening of the circuit. That which remains in the core is called the *residual charge*. With large magnets this may be broken up by a very sudden reversal of poles.

Projection of the core beyond the ends of the coils of wire gives a stronger magnetic effect.

Providing the core has sufficient thickness for the development of magnetic effects, it does not seem to matter whether it is solid or hollow.

For a given weight of iron, a bundle of wires will give a better effect than the same weight in the form of a single bar.

880. Electromagnetic Motors.—Various plans for the adaptation of electromagnetism to the construction of motors have been devised. Among these machines one of the early forms con-

sisted of a coil of wire around a hollow case of pasteboard. In the interior of this there was a rod of soft iron six or eight inches longer than the core. The arrangement being placed with this rod in the vertical position its top just above the coil, on passing a current it was raised, on breaking it fell, so a reciprocating motion was obtained, which by a crank could easily be converted into one of rotation.

Another method was to use a horseshoe electromagnet, the keeper attached to a crank movement of a wheel. The instrument made and broke the circuit itself. The circuit being made the keeper was attracted; the moment it nearly reached the magnet the former was broken, magnetism was lost, and the momentum gained by the wheel carried the latter to the opposite limit of movement, when the circuit was again closed and the keeper attracted—thus a movement of rotation was established.

In modern machines a number of electromagnets are arranged upon the circumference of a wheel. Each of these acts through a very small distance, but the deficiency in this respect is made up by their number.

The exceedingly small distance through which magnetic attractions exert their greatest efficiency has been the chief difficulty in the way of the application of electromagnetism as a motor.

881. **Cost of Magnetic Motors.**—Until quite recent times, the cost of producing electricity by oxidizing zinc in a battery has prevented the use of this agent as a motor. At present, however, improvements in its development from motion, and also in electromotors, render it quite possible that we are on the eve of its application as the motor on our elevated railways, and for numerous purposes in the arts and manufactures.

Even at present, where small mechanical effort is required, or the production of effects at a distance, as in the telegraph, electromagnetism cannot be supplanted.

882. **Electric Bells and Clocks** consist in the adaptation of an electromagnet to the mere sounding of an alarm by the rapid making and breaking of a current; or to the regular make and break as in the beat of seconds; or to controlling the movement of the pendulum by currents from a clock at a central station. In some instances signals are transmitted at regular intervals, and the minute hand moves over two or three minutes at once.

A continuous circuit from a gravity battery is found to work the best, the signal being given by breaking the current.

883. The Morse Telegraph.—Though the discussion of the telegraph is properly outside of the limits of a work on medical physics, yet its universal use makes it necessary that we should say a few words regarding the principles and facts involved in the Morse system.

It consists, 1st, of a *battery and its circuit of wire.* The battery varies in different countries, some form of the Daniell is perhaps best. The wire is of galvanized iron, suspended by insulated glass supports on poles or posts. But one wire is required, the return current at both distant and near stations being delivered into the earth, which acts the part of a common reservoir.

2d. A *communicator* for sending the signals, consists of a horizontal lever by which the circuit is closed and opened, and signals at the distant station produced. These consist of dots and dashes. If the lever gives only momentary contact, a dot is formed; prolonged for a time, a dash is the result. By a combination of these the letters of the alphabet are made up, as follows:

A	B	C	D	E	F	G
.—	—...	.. .	—..	.	.—.	——.
H	I	J	K	L	M	N
....	..	—.—.	—.—	——	——	—.
O	P	Q	R	S	T	
. .	.....	..—.	. ..	...	—	
U	V	W	X	Y	Z	&
..—	. .—	.——	.—..	.. ..	... .	. ...

1	2	3	4	5
.——.	..—..	...—.	....—	———
6	7	8	9	0
......	——..	—....	—..—	———

PERIOD.	COMMA,	SEMICOLON ;	QUOTATION " "
..——..	.—.—	.—.—.	.—.—.—.—
EXCLAMATION !	INTERROGATION ?	PARENTHESIS ( )	PARAGRAPH ¶
———.	—..—.	.—..—	————

3d. The *relay* or secondary battery, which receives the signals and imparts to them additional force, enabling them to work the indicator.

4th. The *indicator*, which receives signals from the relay and records them upon a strip of paper passing under the point of its pencil.

5th. The *sounder*, by which the clicking or noise caused by the movement of the keeper of the electromagnet is increased, has now come into general use, and replaced the indicator on many lines. In this case the message is read by sounds alone.

884. The Needle Telegraph is virtually a vertical galvanometer with an astatic needle, or a single one formed of several pieces of strongly magnetized steel. This works within a bobbin of wire, and carries a light index outside indicating its movements.

These are made by passing the current through the multiplier in different directions by means of a commutator. The deflections are to the right or left, thus producing the letters.

885. Reactions of Currents upon Currents and Magnets were first investigated by Ampère. Their consideration properly belongs to dynamic electricity, but since their application is chiefly in explanation of the action of the compass needle, we have deferred their examination to this point.

The apparatus used for demonstration of these laws consists of wires bent in rectangular and circular forms. One is suspended to move freely, while the other is placed in any required fixed position. Also of magnets freely suspended, or fixed, as the case may be.

The leading facts are as follows:

1st. Two currents parallel, and in the same direction, attract one another.

2d. Two currents parallel, but in contrary directions, repel each other.

3d. A finite movable current, approaching a fixed infinite current, is acted on to move in a direction parallel and opposite to that of the latter; if the former tends from the fixed current, it is acted on to move parallel to it and in the same direction.

4th. The earth exerts a directive action on closed currents movable about a vertical axis; the current places itself in a plane perpendicular to the magnetic meridian, so, for an observer looking at the north, it is descending on the east of its axis of rotation, and ascending on the west.

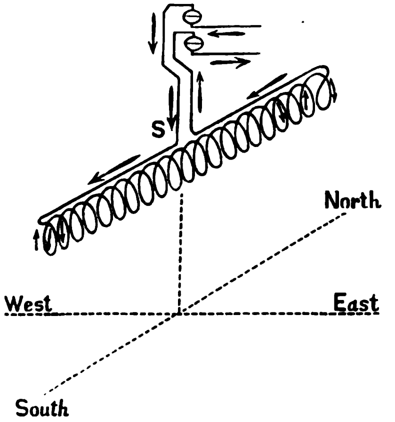
5th. A magnet movable and the current fixed, the former sets itself at right angles to the latter.

886. Solenoids.—A wire wound in a long spiral around a bar of soft iron imparts magnetism to it when a voltaic current passes. If the spiral coil alone is taken without the core, and the wire conveying the current passes down the centre of the helix, the arrangement being freely suspended, it will take up a north and south position, and exhibit true polarity. This ar-

rangement is called a solenoid, S. It may be defined as a combination of a sinuous with a rectilinear current.

If the north pole of one solenoid is presented to that of another, they repel each other. If a north to a south, they

FIG. 362.



The solenoid.

attract. In like manner, if the north pole of a magnet be presented to that of a solenoid, it is repelled; if to the south, it is attracted.

887. **Why the Compass Needle Points North.**—As the culmination of his work on electric currents, Ampère gives the following theory of the magnetic needle, and the reason it points to the north. The process of reasoning is as follows:

1st. The molecules of all magnetic substances are traversed by closed electric currents, free to move about their centres.

2d. When the substance is magnetized these are all coerced into a parallel direction, the stronger the force the more perfect their parallelism. When all are completely parallel the substance is said to be saturated.

3d. The effect of the preceding action is as though a single strong current traversed the exterior of the magnet, which may now be regarded as the equivalent of a solenoid.

4th. The presentation of various parts of the equatorial regions of the earth's surface in succession to action of the sun, develops in its surface thermoelectric currents which circulate around the globe from east to west, very nearly in the course of the equator.

5th. These exert a directive force upon magnetic needles, for they come to rest if freely suspended, when the currents on their

under surface are parallel to the terrestrial. Since the axis of the needle is at right angles to its currents, it, therefore, points to the north.

888. Paramagnetism.—Iron, cobalt, and nickel are, properly speaking, the three magnetic bodies, when submitted to the action of an ordinary artificial magnet. But, if in place of an artificial, a powerful electromagnet is used, we then find that a great number of substances will, like iron, set themselves in the line of the two poles. These are called paramagnets. Those which do not are nevertheless acted upon, and set themselves across this line, or equatorially. They are diamagnetics.

Among those included in the paramagnetic group are iron, cobalt, nickel, manganese, platinum, cerium, osmium, and palladium. Glass, according to its composition, may be paramagnetic or diamagnetic. Also, many kinds of paper, sealing-wax, fluorspar, graphite, charcoal, etc.

Among liquids are solutions of iron, cobalt, nickel, etc. Tubes containing these set themselves axially between the poles when a current is passed.

The effect of magnets on these liquids is seen by placing them in thin watch-glasses between the poles, and directing a beam of light upon them. According as their form changes, the light is converged or dispersed.

Among gases, Faraday found that oxygen was magnetic under ordinary circumstances.

The condition under which a body is examined affects its relations. Oxygen, for example, becomes diamagnetic if its temperature is raised. A substance paramagnetic in vacuo, may be diamagnetic in air.

889. Diamagnetism.—All bodies which set themselves equatorially to the line connecting the poles of the magnet are included in this group.

Among metals are bismuth, antimony, zinc, tin, mercury, lead, silver, copper, gold, and arsenic. Their action is in the order given, arsenic being most feeble. In addition, are rock crystal, alum, glass, phosphorus, iodine, sulphur, sugar, and bread.

Among liquids, are water, blood, milk, alcohol, ether, oil of turpentine, and most saline solutions.

All flames or heated gases are diamagnetic. Faraday mingled gases with visible vapor, and allowed them to ascend between the poles of a magnet and observed their deflections. He found that while oxygen was paramagnetic, nitrogen was diamagnetic, and hydrogen most diamagnetic. Iodine also shows the latter reaction well marked.

890. Diamagnetic Illustrations.—A copper rod freely suspended sets itself at once equatorially between the poles. A copper cube set in rapid rotation between the latter, ceases to move the moment electricity is sent through the bobbins. A circular thin disk of copper, set in motion on an axis by a suitable system of cog-wheels, stops when the current passes. The flame of a piece of resin or camphor placed beneath the pointed poles is thrust aside the moment the circuit in the electromagnet is closed. It looks as though it were blown down upon from above, so strongly is it driven away.

891. Action of Magnet on Polarized Light.—Two powerful electromagnets are placed with their axes in the same straight line. The centres of their iron cores are perforated. A source of light is placed opposite the opening at the end of one, and in this a Nicol prism is inserted. A beam of polarized light is thus introduced into the apparatus; between the poles of the magnets a block of ordinary or flint glass is placed, and in the opening at the further end of the second magnet a Nicol analyzer. The two Nicol prisms are crossed so that light does not pass. The current is then sent along the wires, when at once colored light passes through the apparatus, the tint changing as the analyzer is turned.

Faraday assumed that this action was the result of the effect of magnetism on the polarized ray; while Becquerel attributes it to action of the magnet upon the molecules of the body placed between the poles.

CHAPTER LII.

FARADAIC OR INDUCED CURRENTS.

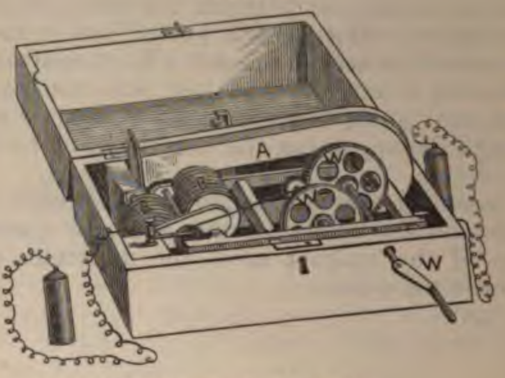
Currents induced by magnets—Currents produced by electromagnets—Inductorium—Experiments with inductorium—Geissler's tubes—The telephone—Dynamoelectric machines.

In 1832, Faraday discovered that instantaneous currents of electricity are produced in wires placed, 1st, under the momentary influence of metallic conductors traversed by electric currents; 2d, under the influence of powerful magnets; 3d, the action of the earth itself.

892. Currents Induced by Magnets.—Conceive that we have a hollow coil of wire connected with a galvanometer. If into the interior of this a strong magnet is suddenly introduced, a momentary current is produced, as shown by the needle of the galvanometer moving and instantly returning to zero. When this ends the current ceases. On suddenly withdrawing the magnet it is again produced, but this time in an opposite direction to the first experiment. Again it only lasts while the magnet is moving, and is strongest when the latter moves quickly.

In the previous experiment an oscillating motion is employed, but in practice a more satisfactory way of producing the result is adopted. Take a powerful compound horseshoe magnet, A, and let two keepers, B, be arranged to revolve rapidly opposite

FIG. 363.



Medical magnetoelectric machine.

one side of its poles by means of the winch and multiplying wheels W W W. When one is opposite the north pole of the magnet, that end will have strong south magnetism induced in it. When opposite the south it will in like manner have strong induced north magnetism. The same will be the case with the other keeper, as they are mounted on the same axis. By rapid revolution they are alternately magnetized, demagnetized, and reversed. If around each a coil of fine insulated wire is placed, the magnetization and demagnetization of the soft iron core will have the same result as though a magnet was suddenly introduced into the coil, and as quickly withdrawn—that is, currents will be induced therein, and they will alternately run in opposite directions.

Though each is exceedingly feeble, and will scarcely give either a spark or shock, yet when they follow each other with

great rapidity they cause very profound physiological effects, and are employed for medical purposes.

In the primitive form of the apparatus we have here described, the direction of the current is continually alternating. By means of suitable contrivances called commutators, these may be made to take the same course, and yield a uniform current in a fixed direction.

893. Currents Produced by Electromagnets.—In this case the apparatus consists of the following parts: 1st, *a battery and circuit*; 2d, *an interrupter*; 3d, *the primary coil*; 4th, *the secondary coil.*

The battery employed is usually a Grenet, worked by the electropoion fluid.

From this the wires pass to a small magnet called the interrupter, the function of which is to open and close the circuit. When the keeper is attracted, the circuit is opened. The magnetism being then lost, a spring raises it, and the circuit is closed, when again the keeper is attracted and it is broken. Sometimes this motion is accomplished by an inverted pendulum, which has the advantage of giving very slow movement, or an exceedingly rapid one.

From the interrupter the wire from the battery or the primary current passes to the electromagnet, where it is wound spirally in an insulated coil around a soft iron core, consisting of a bundle of iron wires. Whenever the circuit is closed, the bundle becomes a powerful magnet; when opened, the magnetism is lost. It is introduced, or withdrawn partially, or wholly at pleasure; a slight introduction gives feeble magnetism, complete, strong magnetism and a powerful current.

Outside of this primary circuit and its enclosed iron core, another insulated coil of exceedingly fine wire, several hundreds yards in length, is wound. When that in the interior is magnetized by the primary circuit, a current is instantly established in the outer coil. When magnetism ceases another instantaneous current runs in the opposite direction in the latter.

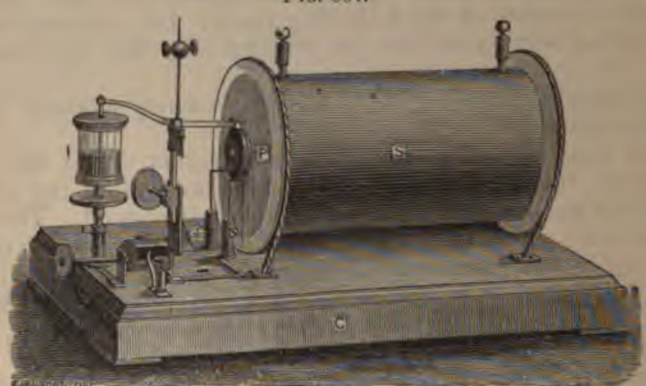
This is the *induced, magnetoelectric*, or *Faradaic current*. As explained, it continually alternates as regards its course. It is employed for medical purposes, and the power of its action may be made to differ, either by variation in the rate of oscillation of the keeper, or by the extent to which the core of the magnet is introduced.

894. Inductorium.—The apparatus described (893) will scarcely yield a visible spark, though it gives very powerful physiological results. By an improved form, sparks of considerable length are obtained, and its power vastly increased. Such an arrangement is called an inductorium or Rhumkorff coil.

The great increase of power in the inductorium is due, 1st, to the introduction of a condenser, C, into the primary current; 2d, to the manner in which the secondary coil S is wound; 3d, to its careful insulation; and, 4th, to the method by which the current in the primary circuit from the battery is broken.

The battery employed for a coil capable of giving a ten inch spark, is half a dozen large sized electropoion cells, its zincs

FIG. 364.



Inductorium.

six by eight inches, and at least two in each cell. A Bunsen battery, with elements of the largest size, may be employed.

From the battery the current passes through the interrupter I, through the coil of the magnet +—, and the condenser C. The latter consists of a great number of sheets of tinfoil and paper soaked with resin. These are laid in alternate layers, with the tin sheets insulated from each other by the paper. The ends of the alternate layers of tinfoil project first on the right and then the left of the pile, when completed. The former are connected with one wire from the battery, the latter with the other. Each sheet of tin presents a surface of about half a square foot. In the largest coils the condenser presents a total surface of some seventy-five square yards. Its action is to receive the extra current produced each time the circuit is broken, and utilize it in an instantaneous demagnetization of the bundle of soft iron wire. For the best effect—that is, production of the longest spark—the contact is broken by a stroke of a small hammer. It is also interrupted by an electromagnet, where sparks in rapid succession are required. The surfaces at which contact is broken are of platinum.

The secondary coil sometimes contains as much as 280 miles of very fine wire, which is not only itself carefully insulated, but

each coil therein is separated from the next by a layer of shellac. Between the secondary and the primary there is a glass cylinder, making the insulation as perfect as possible.

895. Experiments with Inductorium.—Induced currents are produced in the coil each time the circuit is opened and closed. That on opening is short in duration, but of high potential. That of closing, of longer duration, and lower potential. The actions are physiological, chemical, calorific, luminous, and mechanical. The *physiological* effects are sufficiently intense to prostrate a person. A large coil worked by two Bunsen elements will kill a rabbit, and doubtless with a larger number would destroy a man.

The *calorific* properties may be shown by intervening a very fine iron wire between the two polar connections of the induced currents. It is instantly melted. If two fine wires are attached to these poles and then touched to each other, the negative alone melts.

The *chemical* effects vary according to the shape and direction of the platinum poles from each other, and the degree of acidity of the water. Luminous effects with or without decomposition appear. In the latter mixed gases are present at either or both poles. Passed through air its nitrogen and oxygen combine.

The *luminous* effects also vary. In air the longest spark thus far obtained is forty-two inches. This is greatly intensified when a secondary condenser is put upon the induction current. In vacuo, experiments with the electric egg are very beautiful, especially as regards stratification of the electricity. The positive pole is the most brilliant, its light is a fiery red; while the negative is a feeble violet, and extends along the length of the negative rod.

The *mechanical* effects consist in piercing glass plates, sometimes as much as two inches thick. This is accomplished by a series of sparks, not by a single one.

896. Geissler's Tubes.—These are tubes which have been filled with various gases and vapors, and then exhausted. Through their extremities platinum poles pass. The residual gas gives color to the electric discharge as it passes. The striation obtained is sometimes very beautiful. Different kinds of glass and liquids also impart to the electric light varying colors. The spectra of these colored electric discharges are also very characteristic, so that each gas, as hydrogen, oxygen, nitrogen, carbon dioxide, is recognized by the lines of its special spectrum. Light from these tubes has been employed to illuminate the interior of different cavities in the body.

897. The Telephone consists of a steel magnet, some four inches long and half an inch in diameter. Opposite one end is a diaphragm of thin iron. When spoken to, this is thrown into vibration by the voice, and its vibrations cause a rapid shifting in position of the pole of the magnet. Around the latter a coil of wire is wound, the changing of the pole causing a current of electricity therein. This is received by another similar contrivance at a distance, where the operation is reversed, and the rapidly alternating current from the first instrument produces vibrations in the soft iron disk, or diaphragm, and sounds like those received at the other are emitted.

898. Dynamoelectric Machines.—The principle involved in these is somewhat similar to that of the ordinary magnetoelectric machine, and illustrates the conversion of motion or force into electricity. There are many different forms, which we cannot give space to consider. They are operated by steam power, and are made to give light equivalent to many thousands of candle power. They are now extensively used to furnish the currents employed in street lights. These have great intensity, and if, perchance, they pass through the human body, instant death is the consequence.

Another application is in electroplating. In that case the current is manipulated until the positive and negative poles are uniform and fixed.

SECTION XI.

ELECTROBIOLOGY.

CHAPTER LIII.

ELECTROPHYSIOLOGY.

Electricity in plants — Electric fishes — Apparatus for investigating muscle currents—Muscle currents at rest—The frog galvanoscope—Active muscle currents—Nerve currents.

Electrobiology is the study of electricity in relation to living creatures, whether plants or animals, and examination into the effects of electricity upon them. It may be divided into electrophysiology, which deals with their normal electric conditions, and electrotherapy, or the effects of electricity upon them, and its medical application.

899. Electricity in Plants.—Donne, Du Bois-Reymond, Becquerel, and others, have proved, that if one platinum terminal of a galvanometer is inserted into a fruit near the stem, and the other into the opposite part, a current will be obtained. In fruits with pips, as apples and pears, its course is from the stem to the bud; in stone fruits, as peaches and plums, it is in the opposite direction. Prof. Buff has pursued these investigations, and finds that the roots and all parts of the interior of plants filled with sap, are constantly negative; whereas, on the contrary, the humid or moistened interior of the green twigs, leaves, flowers, and fruits, are in a state of permanent positive electrification.

The discovery of these facts led to numerous trials regarding the application of electricity in the culture of plants, but without satisfactory result.

900. Electric Fishes.—The gymnotus or electric eel of South America, the torpedo or electric ray of the Mediterranean, and

the silurus of the Nile, possess the power of giving very strong electric discharges. This is entirely voluntary, and employed for offence and defence. Faraday says, that the shock given by the gymnotus is equal to that of a Leyden battery of 15 jars, exposing a surface of 25 square feet. The first discharge is the strongest, each succeeding one becoming weaker until the creature is exhausted.

In the torpedo, the electric organ is on each side of the head between the pectoral fins and gills. It consists of a series of membranous prismatic tubes parallel to each other, and subdivided by horizontal diaphragms into cells filled with albuminous liquid. Its structure recalls that of the voltaic pile. In all there are from one to two thousand. They are connected with a special lobe of the brain, called the electric lobe.

In the gymnotus the structure of the organ is similar, the prismatic tubes are arranged along the axis of the animal, extending from head to tail.

901. Apparatus for Investigating Muscle Currents.—The requisites are a delicate galvanometer and electrodes which do not become polarized, and will not give a current when placed in contact with tissues, nor in any way alter them while in use. These conditions are met by the electrodes of Du Bois-Reymond. They consist of a glass tube drawn down at one end, and stopped by a pellet made by moistening white clay with a solution of table salt. Saturated solution of zinc sulphate is placed therein, into this an amalgamated zinc wire dips, the other end connected with the galvanometer. Amalgamated zinc in zinc sulphate does not become polarized, and wet clay does not affect muscle.

In addition to these there are various instruments for opening the circuit called keys, as the *mercurial*, *spring*, and *friction keys*, *Pflueger's trip-hammer* and the *metronome interrupter*, a *commutator rheotrope* or *gyrotrope* for reversing direction of current at pleasure; a *rheocord*, for varying its strength by increasing the resistance. These are some of the apparatus with which the electrophysiologist must supply himself to conduct his experiments properly.

902. Muscle Currents at Rest.—The surface of the muscle is called the *natural longitudinal section*; the tendon, the *natural transverse section*. Cuts made longitudinally or transversely are *artificial longitudinal* and *transverse sections*. The clay of one electrode being placed on the natural surface of a living muscle from a recently killed frog, and the other upon its tendon, the galvanometer will at once show a current passing from the one to the other, indicating that the former is positive to the latter. Testing the muscle thus in various positions, it is found that—

1st. Any longitudinal is positive to any transverse section.

2d. A point of a given longitudinal section nearer to the centre of the muscle is positive to one further off.

3d. A point of a given transverse section near the periphery is positive to one near the centre.

4th. The current between two points in any given section is weaker than that between any two in different sections.

5th. Points in the same section at an equal distance from the centre do not give a current.

6th. The smallest fragment that can be used will give the results.

7th. The strongest current is between the centres of the natural longitudinal and the artificial transverse sections.

These facts are explained upon the hypothesis that each muscle consists of regularly arranged electromotor elements, the sides charged with positive, and the ends with negative electricity, enveloped in a conducting medium.

The current is better marked after the muscle has been exposed, but ceases entirely when it is dead. It is, therefore, a phenomenon of life.

903. The Frog Galvanoscope.—A galvanometer is not required for exhibiting these experiments. They may be shown by using another nerve and muscle. For example, if a living muscle be detached, with as long a portion of its nerve as possible attached to it, and the latter is dropped upon another living muscle coming in contact with a longitudinal and transverse section, the former will instantly contract, showing that a current passes between the two sections.

904. Active Muscle Currents.—If a muscle is forced to contract, its normal current at rest is diminished. The effect is so instantaneous that it requires a number of rapidly succeeding contractions to show it; in other words, it must be tetanized. In this condition the galvanometer needle moves to zero, and, finally, takes its position between its original position and that point.

The same result is obtained from warm-blooded animals, though not so easily, on account of the difficulty in keeping these organs alive after removal from the body.

905. Nerve Currents.—Similar effects, though on a much smaller scale, may be obtained from nerves, showing that they have a natural current which, like that of muscle, is diminished by activity in the organ.

CHAPTER LIV.

ELECTROTHERAPY.

General effects of electricity—Static electricity—Constant primary current—Galvanocautery — Electrolysis — Galvanopuncture—Nerve stimulation by constant current—Intermittent primary current—Alternating secondary or Faradaic current—Faradization localized—Electrotonus—Application for resuscitation—Application in diagnosis.

ELECTROTHERAPY is the study of the action of different forms of electricity upon the body, and their application in therapeutics.

906. General Effects of Electricity.—When the electrodes of a powerful battery are taken in the hands, a violent shock is felt, which is greatly increased if they are moistened. If the battery contains 200 Bunsen cells, the shock is very dangerous.

Protoplasm, the basis of all vegetable and animal life, is powerfully affected by action of the electric current, and is forced to contract. If a current of moderate strength is passed through an amœba, it instantly withdraws its processes and contracts into an inactive ball. When this ceases, it resumes its activity and ever-changing form.

When a fresh frog *muscle* is included in a voltaic current, no effect is apparent while the current is passing, but every time it is opened or closed there is contraction.

By a rapidly interrupted current a state of tetanus is produced, the muscle not being able to regain its quiescent state before a new contraction comes on. The amount of shortening shown under these conditions, in a general way, increases with increase in the current.

The action of the electric current upon a living nerve is to add to its activity, whatever its function may be. If it goes to a muscle, it will be forced to contract. If to the eye, the sensation of light is produced, If to the tongue, that of taste, and so on, the manifestations taking place when it is closed or opened.

The forms to be considered: 1st, static electricity; 2d, the continuous battery current; 3d, the intermittent primary or battery current; 4th, the Faradaic secondary or magnetoelectric current.

907. Static Electricity.—Electricity first employed in medicine was entirely of this form. The difficulty in the way of making

the apparatus work in damp weather, caused this method to yield place to currents obtained from the magnetoelectric machine. The recent introduction of the Holtz machine has, however, brought static electricity into use again for certain purposes.

Electricity from the Holtz, Fig. 338, is applied by bringing the hand in contact with one of its poles, and then by means of an insulated conductor placing the other pole in juxtaposition with other parts of the body. The character of the discharge varies according to the manner of application.

1st. *The aura.* A single point or a number of points being made the movable terminal, Figs. 325, 376 F, when this is brought in the vicinity of the surface of the skin it feels as though a gentle breeze were playing upon the part. Such a discharge is very pleasant, and would doubtless be exceedingly grateful in many forms of superficial inflammation.

2d. *Sparks from points.* Bringing the point, Fig. 375 C, in closer proximity to the surface until visible sparks pass, these possess a pungent irritating character, which after a time becomes intolerable, and, if continued, cause local inflammations.

3d. *Sparks from knobs*, Figs. 323, 376 D E. These are an inch or more in length; they produce spasmodic contraction in the parts upon which they are delivered.

4th. *Leyden vial sparks*, Fig. 334, have in a general way the same action as the preceding, though exaggerated. From a battery of sufficient size they can be made sufficiently effective to prostrate the person receiving them.

908. Constant Primary Current.—This is a continuous current from any form of voltaic battery. It should consist either of two cells of large size employed for cauterizing, or of twenty or thirty for electrolysis. The large cells can be stowed away in smaller space by subdividing the zincs, and its action made more constant by agitating the elements in the electropoion. A current of dynamic electricity may be used, 1st, for cautery; 2d, for electrolysis; 3d, as a nerve stimulant; 4th, as an intermittent current. The electrodes are commonly known as *rheophores*, the term being applied to the terminations of the wires for conveying the current.

909. Galvanocautery.—The apparatus consists of a platinum wire about one millimetre thick, bent into a close loop, and flattened to form a knife edge L, Fig. 365. The current from two large cells sent through this readily raises it to a red heat. It is useful for drawing lines along the skin, to destroy granulations, to open abscesses and fistulas, to cauterize prolapsus recti. The current is turned on and off the wire by pressure of the thumb upon a button, R.

The pain during the application is severe, especially if the instrument is moved slowly. After the operation it is slight, secondary hemorrhage never occurs if it is properly performed. Cicatrization is rapid.

Fig. 365.

Galvanocautery holder.

Adjust the current to make the wire white-hot in air, stop the current, apply it cold, and then increase it a little beyond the first adjustment, to make up for loss of heat by action of the tissues. The heat must not exceed a bright white, or the wire becomes enveloped in hydrogen, its styptic action on the blood is lost, and secondary hemorrhage is apt to follow, this also happens if the galvanocautery is moved too fast over the surface.

Figs. 366 to 370, inclusive, represent different forms of platinum wires flattened and bent, which can be attached to the staff, Fig. 365.

The galvanomoxa is a very thin porcelain capsule, around which a thin platinum wire is wound spirally; or a spiral of flattened platinum wire, Fig. 371.

The galvanocaustic loop for removal of polypoid growths is a thin platinum loop, Fig. 372, the ends passing through an insulating handle. Its size can be increased or diminished. It is admirably adapted for removing pedunculated tumors from the rectum or vagina. The current is adjusted by operating upon a piece of raw meat, of equal size of that operated upon. It can be introduced cold, and when all adjustments are made the current is turned on.

Fig. 366.

Fig. 367.

Fig. 368.

Fig. 369.

Fig. 370.

Fig. 371.

Fig. 372.

Galvanocaustic loops.

Dr. Harrison Allen[1] gives the following description of his improved galvanocautery and wire snare for removing polypoid growths from the nasal cavity and larynx.

FIG. 373.

The galvanocautery snare described in the text:

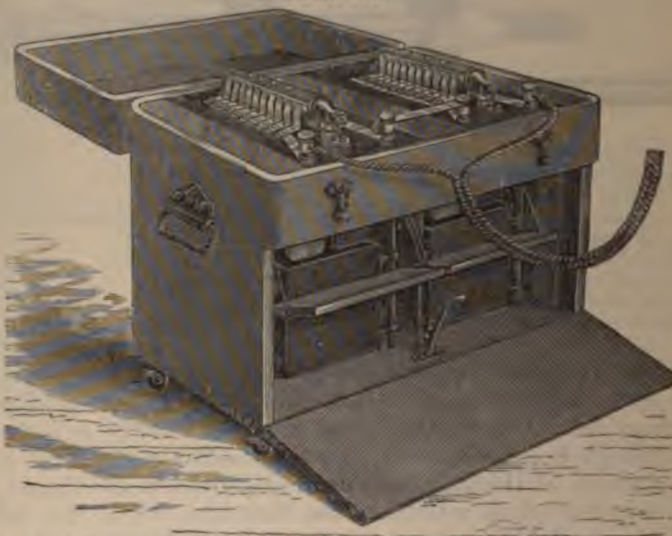
1. The cable of the battery.
2. The canula (which is not shown in full length).
3. The platinum wire.
4. The vulcanite carriage, with screws holding the ends of the platinum wire in metallic contact with the hinge-connections, by which the current is transmitted from the battery.
5. A slotted barrel of aluminium.
6. A movable nut on the screw.
7. A small portion of the screw disengaged from the slotted barrel.
8. Milled stationary screw-head.

It is well known that a loop of wire steadily narrowed has great power in severing the attachment of tumors and other growths. When of a large size, it is sufficiently powerful to pass through bony structures, as well as softer parts of the body. The principle of the snare has been employed in the throat, ear, and nose; but when attention was first directed to this subject the forms available were too large and heavy for the delicacy of manipulation demanded in removing small tumors lodged in the narrower recesses of the nose. Moreover, no snare constructed at that time would permit a galvanic current to pass through the loop while it was being narrowed. It became necessary to devise an instrument which would be light, of small size, and yet sufficiently powerful to remove that class of hypertrophied tissues and polypoid growths that are of frequent occurrence in the nasal chambers. The instrument Fig. 373 combines these qualifications, and satisfactorily performs this service. The only feature of an essential character which may be said to be novel is that the platinum wire forming the snare is covered with a copper coat, excepting that portion forming the loop, which is bare. The current from the battery is conducted through a double canula by means of the copper. The length of the instrument is about nine and a half inches, and its weight less than half an ounce. It has the advantage of securing a rapid and painless operation, without hemorrhage. Sessile (pyramidal) or resilient growths are removed by first burning a groove

[1] A System of Practical Medicine, by American authors, vol. iii. pp. 56, 57.

of any depth into them, after which the loop is drawn while the current is passing. It is evident that failure to remove at least a portion of the growth attacked is an event exceedingly unlikely to occur. Hypertrophies of the inferior turbinated bone can in this way be treated; and if cocaine is freely applied before the operation, it constitutes the most speedy and least painful of any

FIG. 374.



Double battery. The two sets of plates are united by a flat band of metal. The case which encloses the two batteries opens in front, displaying the cells, the plates (pendent over them), and the treadle.

means by which such conditions can be reduced. By using a canula with curved end it is easy to snare growths situated on the posterior portion of the inferior turbinated bone. The current passing through the battery, Fig. 374, to the instrument can be interrupted by any of the numerous devices with which the practical electrician is familiar; or the treadle can be depressed and locked by the lever-catch, and interruption of the current determined by pressure of the finger on the knob of the handle. This is under all circumstances desirable, as the weight of the cells is sufficient to demand considerable force to be exerted by the foot—always enough to destroy delicacy of manipulation.

910. **Electrolysis** is applied for disintegrating urinary calculi in the bladder. The latter is first filled with a solution of nitrate of potash. An instrument resembling a lithotrite, the jaws of which can be separated to grasp the calculus, is then introduced.

The two parts of this apparatus contain an insulated platinum wire, its extremities only bare. Between these the calculus is gripped, and the current from a strong battery sent through the wire. The nitrate of potash is decomposed, nitric acid liberated at one pole attacks the calculus, and disintegrates it. Having done its work, it is neutralized by the potash set free at the other. The bladder should be moderately full of fluid, and the calculus kept during the operation as near its centre as possible.

After a perforation has been secured by the acid in one place, the calculus should be gripped by a fresh diameter, and another made. According to condition of the patient, the operation must be repeated from time to time, until it is completely honeycombed, it can then be readily crushed by a lithotrite, and removed.

911. Galvanopuncture is the application of electrolysis to treatment of aneurisms. It consists in decomposing the blood by a constant current, coagulating the albumen, and furnishing a nucleus upon which fibrin may be deposited. The battery required is twenty to thirty cells of Daniell, or fifteen Grove. The *anode* consists of a fine platinum needle insulated nearly to its point with a uniform covering of ebonite. With this the tumor is pierced. The *cathode* is a large metallic plate covered with wet sponge. This is placed on the thoroughly moistened skin, as near as possible to the aneurism. The artery must be compressed below the tumor, so the clot is not carried off, and the current opened and closed gradually. If it is too strong, bubbles of gas are set free, and the clot is loose and lacks necessary consistency. The operation is continued until pulsation ceases, or gas is detected. The cure is generally effected by inflammation, which sets in immediately or after a day or two.

912. Nerve Stimulation by Constant Current.—The muscles and motor nerves are not affected unless the current is very strong, or its density varies. The sensitive nerves, on the contrary, are strongly acted upon, particularly at the cathode, causing cutis anserina, attended by a burning or prickling. It produces, first, *anæmia*, then *hyperæmia*. In diseased conditions there is a difference between the action of the continuous and Faradaic currents.

Remak asserts *that the constant current exerts an antiphlogistic action, paralyzing the walls of the capillaries of the inflamed part, and so facilitating circulation and resorption.* He recommends its use in acute, chronic, traumatic, or rheumatic inflammations of joints; chronic rheumatism of joints, muscles, tendons, periosteum, and nerves; cramps; inflammation of spinal cord, attended

by hemiplegia; inflammation of cerebrum attended by tremors and convulsions; and for painful and inflamed tumors. The cathode is placed on the inflamed part, and the anode near by. If there is water exudation, the application is reversed. Other authors deny that the constant current is superior to the induced in these cases.

913. Intermittent Primary Current.—We have the following forms of paralysis to be subjected to treatment:

1st. That in which neither the will nor either form of electric current can act on the irritability of muscle or nerve.

2d. When the action of the will is preserved in part, and yet neither current can affect either muscle or motor nerve.

3d. Where the will has lost all power, yet both forms of electric current act, though with diminished force.

4th. Where both the will and the induction current are powerless, while the intermittent constant current acts.

In the last condition we find:

A. During absence of motility.

1st. The constant currents are so effective, that those too feeble to have any action on normal muscles give strong contraction.

2d. During treatment this power rapidly reaches a maximum, then diminishes.

3d. In many cases contraction is obtained not by stimulating the motor nerve, but the muscle itself.

B. Motility returning.

Irritability for constant currents diminishes, as that for the will, and induced currents rises.

The intermittent primary current is of especial use in modifying the irritability of muscles and nerves. The simplest rule to follow in the use of this and other currents is, employ that having the best effect.

914 Alternating Secondary or Faradaic Current.—The parts between the poles are all traversed by currents which converge to the point of application of the poles.

The quantity of electricity at all cross-sections of the part traversed is the same. Convergence at the points of application causes greater intensity of action and sensation, owing to the termination of the nerves of sensation in the skin. To avoid undue stimulation of the latter, we must enlarge the size of the electrode.

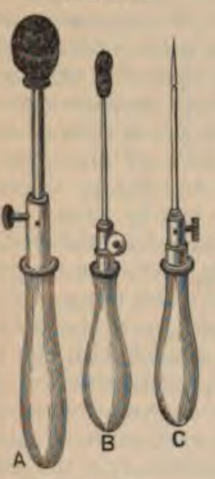
When the skin is dry, the current passes almost entirely through sweat glands.

According as a larger or smaller extent of surface is included in the electric current, the electrodes represented Fig. 375 are employed: A large sponge, B small sponge, C pointed and gilded.

Other forms, Fig. 376, are also employed; they are, D small knob gilded, E large knob gilded, F wire brush.

To excite cutaneous nerves alone, the large electrode of wet sponge must be applied to the moist skin, and the wire brush drawn gently over the dry skin of the part treated.

FIG. 375.



Electrodes.

FIG. 376.

Knob and brush electrode.

To excite a muscle alone, place the large sponge over the belly of the organ, then press the small point firmly over the entrance of the motor nerve into the muscle. The patient should be recumbent.

915. Faradization Localized.—The following detailed directions are from Morgan's work:

Head. The *trunk of the facial* nerve is stimulated by placing the anode on the point seen inside the ear-shell, or concha, and the result is the entire face; half is drawn toward that side, the skin thrown into countless wrinkles, the eye shut, and the nose and mouth drawn obliquely downwards. The stimulation of the *auriculo-posterior branch* of the facial nerve, at a point in front of the mastoid process of the temple bone, is very painful, and causes contraction of the *retrahens* and *attollens auriculæ*, drawing the scalp downwards, and raising the concha backwards and upwards. The muscles of the ear are too unimportant in man to detain us any further. The branch of the facial going to the *stylo-hyoid* and *digastric* m. is rarely reachable, save in very emaciated persons; and, if reached, the result is the movement of the *os hyoides* outwards, backwards, and

upwards. The *frontalis* m. can be stimulated by itself *extra-muscularly*, the branch it gets from the facial nerve being very superficial, and, in contracting, it throws the brow into horizontal wrinkles, curved somewhat downwards in the median line. The *corrugator supercilii* m. is also stimulated extramuscularly, and flattens and depresses the eyebrow, and draws its base inwards and downwards. The *orbicularis palpebrarum* m., stimulated extramuscularly, shows the eye and wrinkles up the eyelids. The *zygomatic major* m., stimulated extramuscularly, draws the angle of the mouth outwards and upwards, and produces on the cheek deep wrinkles, radiating outwards, from this angle. The *zygomaticus minor* m. requires intramuscular stimulation; is painful, and marked by the drawing of the upper lip upwards and somewhat outwards. The *levator labii superioris proprius* is difficult to reach, even intramuscularly; the upper lip rises almost vertically, uncovering the teeth. The *levator labii superioris alæque nasi* is easily reached, but with pain, and lifts the upper lip and the wing of the nose. The *compressor nasi* and *pyramidalis nasi* must be stimulated together, giving on the nose wrinkles parallel with the back of the latter, and at the root short, thick, horizontal, or slightly oblique wrinkles, while the eyebrow is drawn downwards and inwards. The *dilator narium anterior* and *posterior* are very rarely of any significance. The *orbicularis oris* m. has four motorpoints; and, hence, to be thoroughly stimulated, would need four electrodes; its mode of action is self-evident. The *buccinator* m., when it contracts, draws the cheek against the teeth, and shortens the upper and lower lip half. The *triangularis menti* m., when it contracts, draws the angle of the mouth downwards and strongly outwards, lengthening the opening between the lips, but not causing them to separate from one another. The *quadratus menti* m. draws the corresponding lip half downwards, and somewhat outwards, and presses it firmly against the teeth. The *levator menti* m., stimulated extramuscularly, pushes the lower lip forwards. The *masseter* m. is stimulated by placing the electrode in the *incisura semilunaris*, between the coronoid and condyloid processes of the lower jaw; and the *temporal* m., by placing one electrode on the posterior and the other on the anterior segment of the muscle, and the result is, the lower jaw presses up against the upper one with great force. The *tongue* stimulated on one side, shortens and curves towards it, and, if stimulated on its under surface, is drawn quickly into the mouth again. Using two electrodes, the *velum palati* is drawn backwards and upwards. The *azygos uvulæ* m. is stimulated by placing the fine-pointed electrode gently at the root of the uvula, and the latter disappears almost from sight. The *superior*, *middle*, and *inferior constrictor* of the pharynx are also within reach.

Neck. In examining this region, the patient's face must be made to look towards one shoulder, and its position should be the same at every sitting.

The *subcutaneous colli* m., or *platysma myoides*, requires the anode to be set near the middle of the inner margin of the sterno-cleido-mastoid muscle and the cathode on the subcutaneous colli branch of the facial nerve, and, drawing on the lower lip and jaw, it may uncover the teeth, etc. The *nervus accessorius Willisii* is easily reached, since, on emerging posteriorly from the sterno-cleido-mastoid (to which it here gives off a branch), it is, until it enters the *trapezius* m., very superficially situated; and, both these contracting simultaneously, the neck is bent, the lower jaw, protruded, the head twisted toward the shoulder, which is strongly raised and drawn backwards and inwards. The *sterno-cleido-mastoid* m., on being stimulated by itself by placing the electrode somewhat lower down, draws the head down so that the ear faces the shoulder, whilst the face looks somewhat upwards, backwards, and to the opposite side. The *trapezius* m. is best acted on by placing the anode on the nerve, entering the muscle about a half inch below the accessorius Willisii nerve, and we get either a raising of the shoulder backwards, with drawing of the scapula towards the spine, or a pulling of the head backwards and outwards, or both motions, according to the action of the antagonists of the trapezius muscle on the head or shoulder. The isolated stimulation of the *levator anguli scapulæ* is followed by the drawing of the internal angle of the scapula upwards, inwards, and forwards, whilst the acromion, fixed by the weight of the arm and the action of the antagonists, does not move to any special extent. The *hypoglossal* nerve may be reached just above the *cornu major* of the os hyoides, just in front of the *hyo-glossus* m., but its effect is uncertain. The *omo-hyoid* m., when it contracts, draws the os hyoides downwards and outwards. The actions of the *sterno-thyroid* and *hyo-thyroid* are too evident to need description. The stimulation of the *phrenic* nerve (there is no danger in the simultaneous stimulation of both, nor is it painful) for the production of artificial respiration requires quite strong currents and large electrodes, and the anode must be pressed gently, but fixedly, against the outer margin of the sterno-cleido-mastoid, near the omo-hyoid. The result is rapid contraction of the diaphragm, bulging out of the abdomen, and forcible entry of air into the trachea, giving rise to a sobbing sound.

The isolated stimulation of the separate muscles of the larynx is very difficult, and those interested in this subject will do well to consult the works of Voltolini, Mackenzie, and other specialists.

The motor nerves of the shoulder and thorax, arising from

the *supraclavicular* portion of the *brachial plexus*, are sometimes, but rarely, reachable for the purposes of isolated stimulation.

The *posterior thoracic* or *dorsalis scapulæ* nerve, when stimulated, causes the *rhomboid* m. and the *serratus posticus superior* m. to contract and draw the scapula upwards toward the spinal column and feebly to lift the upper ribs. The isolated stimulation of the *lateral thoracic*, or *external respiratory* nerve, causes the *serratus anticus major* m. to contract vigorously, thereby raising the acromial angle of the scapula, and pushing this bone very far outwards and forwards, and lifting the clavicle some distance out from the thorax. The *subscapular* m. is most easily stimulated, directly, or else by acting on the subclavian nerves in the posterior part of the axilla. The stimulation of the *anterior thoracic* nerve causes the *pectoralis major* m. to draw the arm far towards the median line.

Upper Extremity. On placing the electrode just above the clavicle towards its outer extremity, the *deltoid* m. is caused to contract. The stimulation of the *musculo-cutaneous* nerve at its emergence from the *coracobrachial* m., in the groove between the latter and the biceps muscle, or at the point between the two heads of the latter, is painful, though it causes the simultaneous contraction of the *biceps* m., and the *brachialis internus* m. The isolated contraction of the *biceps* m. is effected by the use of the motorpoint between its two heads. The stimulation of the *brachialis internus* requires the anode to be placed at the point where the lower half or third of the biceps muscle begins (pushing with the fingers the median nerve aside to save it), whilst the cathode rests on the outer edge of the other muscle. The *median* nerve, though easily reached at any point along the *sulcus bicipitalis*, is best stimulated at the lower third of the humerus, where it can be *fixed* against the bone. The stimulation of this nerve excites peculiar pain in its sensitive cutaneous branches on the hand and fingers, and causes contraction of the *pronator teres* and *quadratus*, *radialis internus*, *palmaris longus*, *flexor digitor sublimus* and *profundus*, etc., producing strong pronation of the forearm, flexion of the hand towards the radial side, flexion of the fingers with opposition of the thumb. The stimulation of the *pronator teres*, by either of its two motorpoints, is quite painful, in consequence of the great number of sensitive nerves on the flexion side of the arm, though the resulting contraction is exceedingly rapid and strong. The *flexor digitor sublimus*, as well as the *profundus*, is only accessible to intramuscular stimulation. The branches of the median nerve going to the *radialis internus* and *palmaris* m., which come off at about the same point from the nerve trunk, also enter their respective muscles at about the same distance from the elbow on their ulnar margins. The *pronator quadratus*, and *flexor pollicis longus*, need

intramuscular stimulation. The motorpoints of the *abductor pollicis brevis*, *opponens pollicis*, and *flexor pollicis brevis*, are superficial and easy to find; this is true in general of the other muscles of the hand and fingers. Though the *ulnar* nerve may be reached at any point from the axilla to the elbow, still the best place to stimulate it is at the groove, between the olecranon and the internal condyle of the humerus, and the result is pain along the course of its *palmaris longus* and *digital branches* on the dorsal side of the hand, and contraction of the *ulnaris internus*, *flexor digitor profundus*, *palmaris brevis*, *interossei*, *lumbricoides quartus*, and *adductor pollicis*. The *ulnaris internus* m., when stimulated isolatedly, directly or indirectly, flexes the hand towards the ulnar side of the arm. The ulnar, like the median nerve-branch, going to the *flexor digitor profundus* m., is not susceptible of isolation.

The *radial* nerve is best reached at the point between the insertion of the deltoid muscle and the external condyle of the humerus, somewhat to the outside of the latter. The branches it gives to the *triceps*, *brachialis internus*, and *supinator longus* are not within reach, so that these muscles must be stimulated *directly—i. e.*, intramuscularly. When the *supinator longus* m. contracts, it flexes the forearm on the arm in a position between pronation and supination, and only really supinates when the forearm is strongly pronated; thus it is in truth a flexor muscle.

The *radialis externus longus* m. only reacts when stimulated intramuscularly; as is also the case with the *supinator brevis* and *radialis externus brevis*. Both the branches the *extensor communis digitorum* receives from the radial nerve should be stimulated simultaneously, to give rise to a complete contraction of this muscle; or, as the skin is not very sensitive here, the component bundles may be acted upon separately, placing, of course, the two electrodes upon the muscle itself. Direct stimulation is also necessary for the *ulnaris externus* m., and the result is, extension of the hand towards the ulnar side of the arm. The motorpoints of the *abductor pollicis*, *extensor digiti minim. propr.*, *extensor indicis propr.*, *extensor pollicis longus* and *brevis* m., are easily found by reference to any anatomy.

Trunk. The muscles of the trunk receive each several nerves, and, hence, cannot be caused to contract generally, nor is it necessary that they should do so.

Of the muscles of the back, some have been mentioned in treating of the neck; of the others, the only ones that can be reached are: the *splenius capitis*, the *latissimus dorsi*, the *teres major* and *minor*, and the *serratus posticus inferior*.

Lower Extremity. The stimulation of the *crural nerve* causes much pain along the track of the *saphenus major*, *minor*, and *cutaneous femoris*, *anterior* and *median*, and on the front and inner side

of the thigh, the knee, and the leg down to the big toe, along with powerful contraction of the muscles of the leg. In emaciated persons, it is often possible to stimulate the chief branch of the *crural nerve*, which goes to the *quadriceps extensor cruris*, and this excites not only that muscle, but also the extensors on the front of the thigh. The *rectus femoris* m. has a motorpoint four to five inches from the anterior superior spinous process of the ilium.

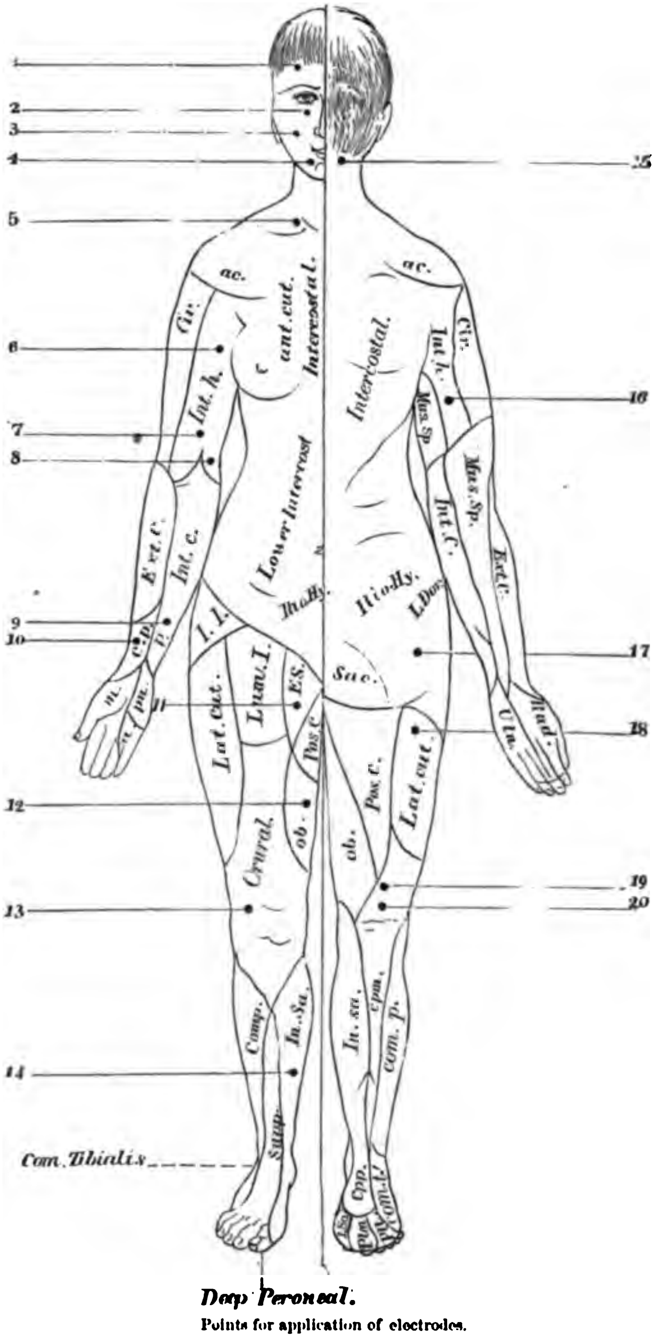
The *vastus externus* m. has two motorpoints two to three inches apart; and it is best to act simultaneously on both with the two electrodes. The stimulation of this muscle is easily effected; but to lessen the pain, it is necessary to push the handle of the electrode towards the other thigh, pressing the nerve of this muscle outwards. The *sartorius* muscle receives several nerves, but it is most advantageous to place the cathode on the upper motorpoint, and the anode on the lower, or on the lower half of the muscle. The *tensor fasciæ latæ* m. receives a branch from the *glutæus superior*, and another from the *crural nerve*, both within easy reach. The stimulation of the *obturator nerve* requires the electrode to be *firmly* pressed on the part, and is very painful, although it gives rise to an exceedingly energetic adduction of the thigh. The *pectineus* and the *adductor brevis* are best stimulated intramuscularly. The *adductor longus* and the *gracilis* are readily reached extramuscularly, and the *adductor magnus* has a very available motorpoint at the inner and posterior part of the thigh. The *glutæus superior* and *inferior*, and the *sciatic nerves*, are rarely within reach, and always need strong currents and pressure. Each head of the *biceps femoris* m. has a motorpoint.

The motorpoints of the remaining muscles may be easily found by reference to any anatomy.

Many of the more important points for application of electrodes are given in Fig. 377, in which the left side presents a face view of the body, and the right a back view. From Bartholow's "Electrotherapeutics." The stimulation of the bladder or uterus is readily effected by introducing in the one case an electrode into the viscus, and in the other applying it to the entrance, and holding a large sponge-electrode against the abdominal wall, or passed up the rectum, or resting against the sacrum.

916. Electrotonus.—In a living nerve, certain parts on the surface are positive to other parts, and will give a current through the galvanometer when intervened in the course of a wire connecting them. Suppose this connection made, then let another portion of the same nerve be included in a voltaic circuit, and let the current pass in the same direction as the proper nerve current. The latter is at once increased though none of that

FIG. 377.



Points for application of electrodes.

1. Seventh or facial nerve filament supplying the frontal muscle.
2. Seventh or facial nerve filament supplying the levator labii superioris alæque nasi.
3. Seventh or facial nerve filament supplying the zygomaticus minor.
4. Seventh or facial nerve filament supplying the orbicularis oris and quadratus menti.

5. Phrenic nerve	supplying the	diaphragm.
6. Musculo-cutaneous nerve	"	biceps, brachialis, etc.
7. Musculo-cutaneous nerve	"	brachialis internus.
8. Ulnar nerve	"	muscles of forearm and hand.
9. Radial nerve	"	flexors of thumb and fingers.
10. Ulnar nerve	"	palmaris brevis, abductor digitor. min., opponens digitor. min., etc.
11. Obturator nerve	"	sartorius, adductor longus, etc.
12. Crural nerve	"	adductor longus, vastus internus, etc.
13. Crural nerve	"	vastus externus.
14. Musculo-cutaneous nerve	"	flexor digitorum com. long.
15. Occipital nerve	"	posterior neck muscles.
16. Circumflex nerve	"	triceps, etc.
17. Intercostales nerve	"	lumbar muscles.
18. Gluteus nerve	"	adductor magnus, etc.
19. Popliteal nerve	"	gastrocnemius externus.
20. Popliteal nerve	"	soleus.

from the battery passes into it. This change in the normal electromotive state of the whole nerve by the passage of a constant current through a portion, is called the *electrotonic state*, and is most intense near the exciting current. It lasts while this is passing. The excitability of the nerve is increased. The part through which it is passing is called the *intrapolar region*. The condition near the positive pole is called *anelectrotonus;* that near the negative pole *kathelectrotonus*.

The excitability of the nerve is diminished in the anelectrotonic region, in the kathelectrotonic region it is increased. Its power to convey a stimulus is also lessened in the first and increased in the second. If, therefore, it is required to diminish the excitability of the sensory nerves in any part, the current should be so passed as to throw them into the anelectrotonic state, and *vice versâ*.

917. Application for Resuscitation.—A powerful electric current passed through the body of a killed animal produces strong contractions of the muscles. In like manner, a Faradaic current will often restore functions impeded in *aphonia* and *asthma*. Even the respiratory function may be restored in asphyxia from chloroform, or opium poisoning, by faradization of the phrenic nerves. This is accomplished by placing one electrode over the scalenus anticus muscle, behind the sterno-mastoid at the root of the neck, while the other is brought in contact with the sixth or seventh intercostal space.

918. Application in Diagnosis is admirably summed up as follows, by J. McGregor Robertson, who says: The electric current is employed, (1) to detect alterations of irritability or sensi-

bility, (2) to aid in distinguishing between forms of paralysis, (3) to detect the presence in the tissues of foreign metallic bodies, (4) to unmask malingerers, (5) as a final test of death.

(1) To test *irritability of muscle* or nerve, use an induction current, and apply well-moistened electrodes to the part, the skin over which is also moist. This insures the current traversing the latter without affecting it. Graduate its intensity by adjusting the secondary coil or altering the extent of surface of plates in action in the cell. Begin with the healthy side, and find the feeblest current that will produce a response on the part of the muscle or group tested. Compare the result obtained with that of a similar experiment on the suspected side, taking care that the experiment is repeated under precisely similar conditions. If both sides are suspected, then a healthy standard must be obtained elsewhere, and the physician must compare his results with an average obtained from healthy individuals.

For testing *sensibility* the skin must be acted on, and not the tissues beneath. Therefore, the electrodes must be dry (a wire brush), and the former well dried and dusted. Then find what strength of current just begins to be painful on the healthy side of the patient, and compare this with the diseased side.

(2) For electrical diagnosis paralysis is considered due either to a *central* or *peripheral* lesion, and the value of electricity is in the aid it gives in distinguishing between these. A *central* lesion is one which separates the muscles from the *higher centres*, a *peripheral* one that cuts them off from their *lower centres*. Thus those of the legs are in nervous communication with centres in the spinal cord, their lower centres; but these are subservient to centres in the brain, their higher centres. Now these muscles may be cut off from their higher centres, their lower being left intact, by a lesion in the brain, or one in the cord above the seat of their lower centres; and in each the lesion would be called *central*. If, however, it is in the cord, affecting the centre from which the nerves supplying the muscles come off, or in the nerves, cutting off communication between the cord and the muscles themselves, it is called *peripheral*. Thus *central paralysis* is dependent upon disease in the brain, or in the cord, higher up than the place of origin of the nerves for the affected muscles, while *peripheral paralysis* is due to disease in the cord affecting the centres connected with the paralyzed muscles, or to disease of the nerves; and this would include injury to them—*e. g.*, cutting, bruising, thus depriving them of nervous continuity.

This being explained, the main fact, stated broadly, is *that nerves and muscles paralyzed by a central lesion have their irritability unaffected, while those by a peripheral have it rapidly diminished and finally abolished.*

In the *central lesion* the nerves and muscles still retain their connection with the centres in the spinal cord. They are only removed from the influence of the will, so that voluntary motion is in abeyance, but the nourishment of nerves and muscles remains, and no sign of any impaired function ought, therefore, to be present. Of course, volition being suspended, their duties are no longer performed. They fall into disuse, and since, in course of time, enfeeblement always attends disease, after an interval, diminished irritability will be perceived. This is, however, directly the result of disuse, and only indirectly a result of the lesion. The irritability can be restored by faradization, which affords an artificial stimulus, and causes the paralyzed muscles to work. So the rule remains that irritability is unaffected by the lesion. There is an exception, however. It occasionally happens that it is apparently *increased.* This will occur when the lesion in the brain or upper part of the spinal cord is an irritative one, and affects the ends of the fibres which it has cut off from their centres. In the absence of any ground for supposing this, a physiological explanation would be that the moderating influence of the higher centres had been removed, and the response of the lower was, therefore, more easily elicited.

In the *peripheral lesion* communication has been cut off with the centres in the cord. These are not only reflex, but trophic; the nerves, therefore, degenerate, and the retrograde changes will in time also affect the muscles. The rapid loss of irritability, then, is due to degeneration. Here a curious circumstance arises, that is difficult to explain. What has been said refers to electricity used as induced currents, applied by moistened electrodes. It is found that in some peripheral lesions, where, as is expected, response to the induced or Faradaic current is entirely absent, the muscles will respond to the galvanic current *if it is slowly interrupted*, and those of the paralyzed side will often respond vigorously to one so weak that it has no effect on the sound side. Further, in such cases the nature of the response is altered. Nominally, excitability is greater in the neighborhood of the cathode on closing, and the anode on opening the circuit; but in these cases it is contraction at the cathode on opening and at the anode on closing that is marked. It is difficult to explain these facts. That offered by Erb and corroborated by Ziemssen is that nerve and muscle respond differently to an electric current; that, while the former responds readily to currents of very short duration, the latter responds more to currents of longer duration, like those obtained by interruptions of the constant current. Consequently, when the irritability of nerve and muscle to faradization has disappeared, the response of the latter to galvanism may still be elicited.

In time, however, if degeneration proceeds, galvanism also fails to elicit contraction. The cases which show these *degenerative reactions*, are *rheumatic paralysis*, *facial palsy* (due—*e. g.*, to cold—*i. e.*, not hemiplegia), *lead palsy*, *paralysis due to injury of nerve trunks*, and others. To sum up, then, in central paralysis irritability is unaffected, in peripheral it rapidly disappears, but in some cases irritability of the muscle to galvanism is increased, and thereafter disappears.

(3) To detect *foreign metallic bodies*—*e. g.*, a bullet in the tissues, the *constant* current is employed. What is required is a *battery* sufficiently powerful to ring an *alarm bell*, and in the same circuit a *probe* of particular construction. This should be of insulating material, having embedded in it, and insulated from one another, two copper wires. Their ends are exposed at the end of the probe. If they are put in the circuit of the battery and bell, the latter will not ring, because contact is broken between the two wires. If, however, the probe be pushed into a wound and come in contact with a bullet, then, both wires touching the lead, the circuit is completed, and ringing the bell gives the indication. Instead of a bell, a galvanometer is used (not one of sensitive construction), its deflection intimating metallic contact.

(4) As a means of detecting *malingerers*, electricity must, of course, be used with caution. If a strong induced current fail to induce contraction, paralysis is evident, for contraction set up by electricity is beyond voluntary control. Though it is produced, it does not follow that nothing is amiss. Faradization of the dry skin with the wire brush, if strong enough, is very painful, but can, without danger, be employed.

(5) Within, at most, two or three hours after *death* induced currents of electricity fail to provoke a response from the muscles. Failure in this is, therefore, a sure sign of death. Moistened electrodes must be employed in the test, and the skin well saturated with warm salt water.

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